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VOL. XLVI

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A quarterly paper devoted to the sugar interests of Hawaii, and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

JANUARY TO DECEMBER

THE HAWAIIAN PLANTERS' RECORD

VOL. XLVI

H. L. LYON, *Editor*

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ORGAN OF THE EXPERIMENT STATION OF THE
HAWAIIAN SUGAR PLANTERS' ASSOCIATION

HONOLULU
1942

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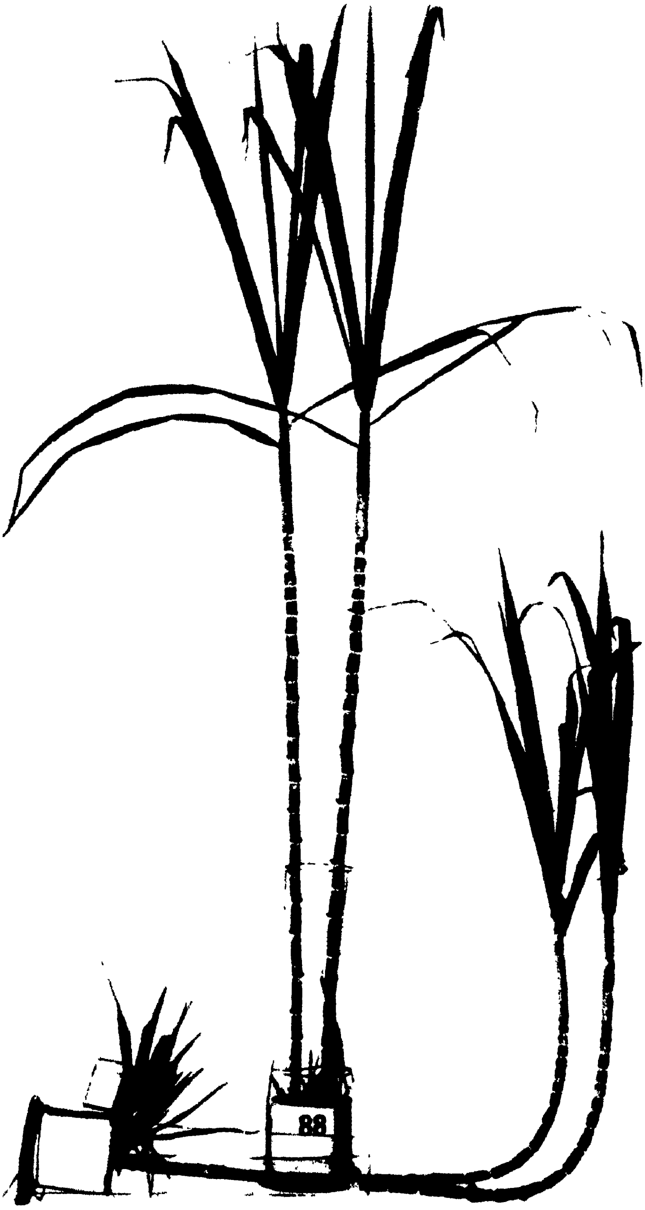
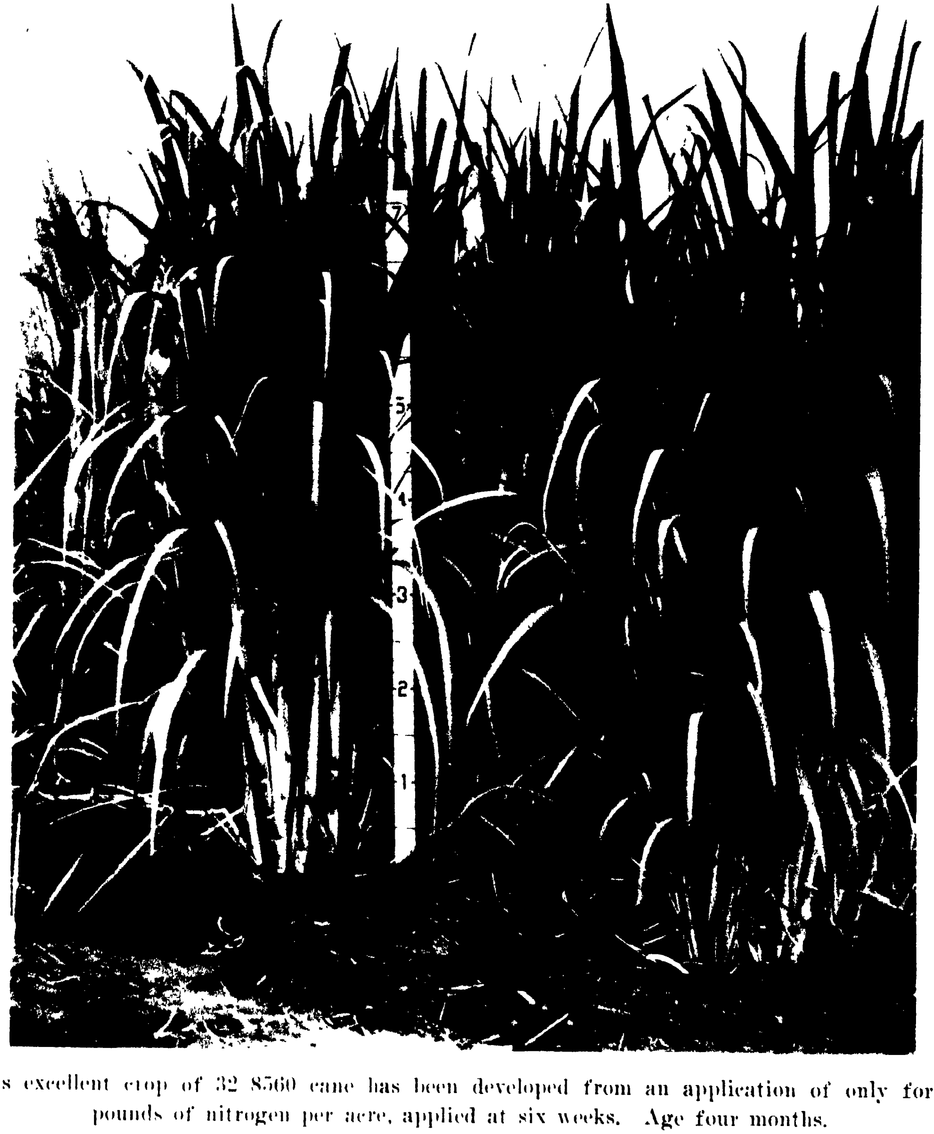
FIRST QUARTER

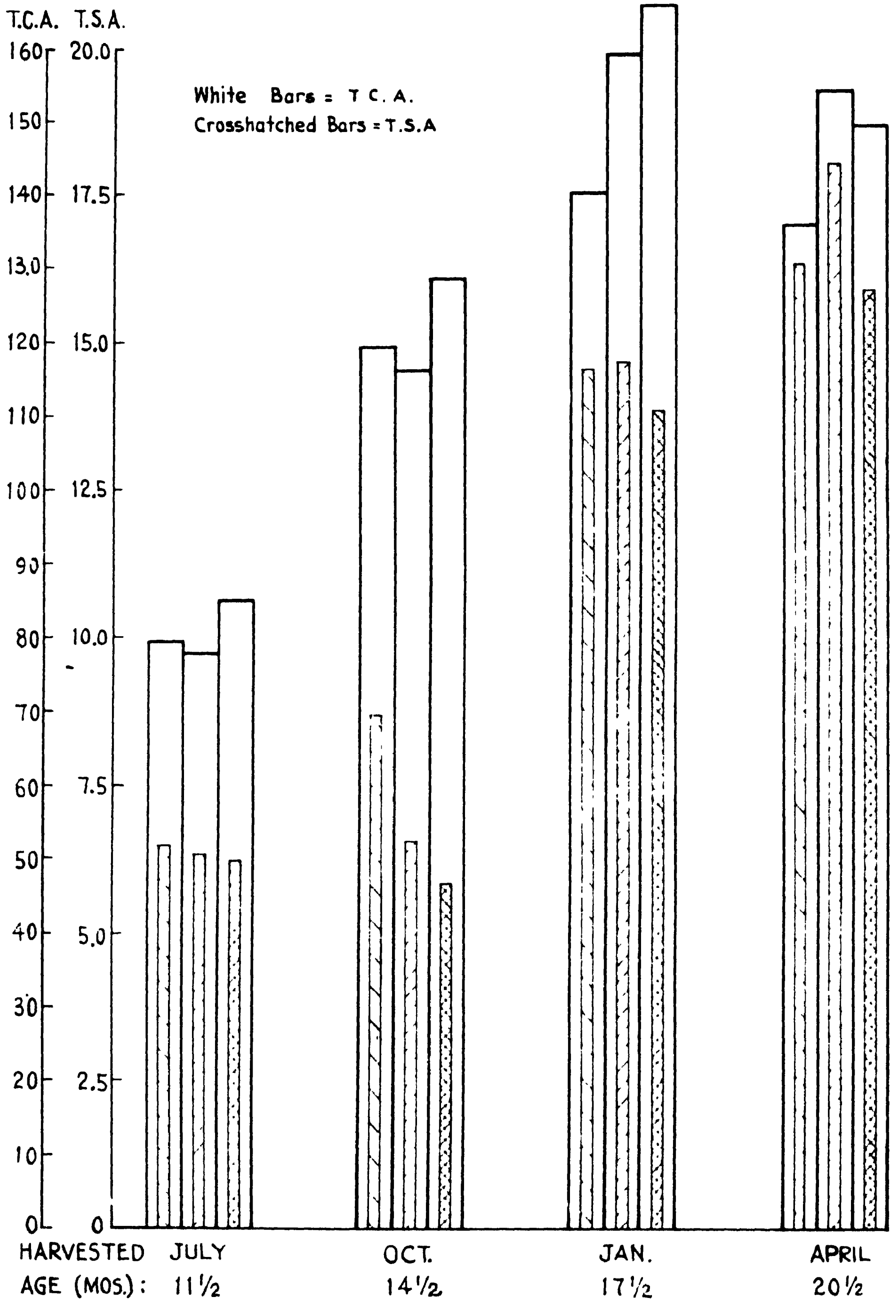


Relative positions at harvest of cane, lodged and erect (control), used in a study of the effect of lodging on juice quality.

THIRD QUARTER



This excellent crop of 32 8560 cane has been developed from an application of only forty pounds of nitrogen per acre, applied at six weeks. Age four months.



In each of four harvests, the yields of 32-8560 cane and sugar are shown as obtained from applications of nitrogen at (left to right respectively) 100, 160, and 220 pounds per acre.

THE HAWAIIAN PLANTERS' RECORD

Vol. XLVI FIRST QUARTER 1942 No. 1

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

Sugar—The Foundation of All Progress on Earth[*]

By Harold L. Lyon

Sugar is the beginning of each and every food. It is the primary source from which the food of all green plants and that of all the higher animals is derived. It is, in fact, the one most important factor responsible for the evolution of all the higher forms of plant and animal life. Man himself would never have come into existence if sugar had not been developed on earth. Now, these may seem to be rash statements, but we shall easily justify them.

Based upon your everyday experience with it, you are apt to think of sugar as something sweet to the taste and easy to take. You visualize it as the stuff which you drop into your coffee or spread on your mush, or as the syrup which you pour over your hot cakes or waffles in the morning.

Should you be asked if you could do without sugar and the products derived from sugar, you would probably say, if you answered promptly, that you could if necessary. However, should you delay your reply until you had determined just what such abstinence on your part would actually mean, you would most certainly return an emphatic "no" for an answer. Your analysis of the proposition would soon lead you to the amazing conclusion but fundamental truth, that absolutely all of the energy which you obtain from the food which you eat and the beverages which you drink is derived directly or indirectly from sugar—it has at one time been locked up in sugar. You may partake of a mixed diet including fish, flesh and fowl, cereals and vegetables, milk, tea and coffee, beer and wine, yet the energy which each supplies reached the form in which you took it by way of sugar. So, if you deny yourself sugar and all the products derived from sugar, you renounce all foods and all drinks except water. You doom yourself to a slow but sure death by starvation.

If now you follow this line of investigation until you determine the whole truth regarding the role which sugar has played in the development of man and his civilization, you will be forced to this most astounding conclusion: all of the energy utilized by man, except that which he gets directly from the heat of the sun and earth or obtains from water and wind power, comes to him through sugar. All of the energy which he derives from the combustible materials in our forests, in the vast coal beds of the earth, in its extensive deposits of petroleum and its huge reservoirs of natural gas, was at one time locked up in sugar.

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[*] An address delivered at the sixtieth annual meeting of the Hawaiian Sugar Planters' Association, Dec. 10, 1940.

Man obtains from his food the energy which he utilizes to heat his system, to operate his organs, to move his body about from place to place, and perform the work necessary to his comfort, pleasure and existence. What is true for man in this respect is likewise true for all other animals. The food which an animal takes into its system consists of complex, chemical compounds built up by some other organism. These represent work done and energy stored up. These complex compounds, the animal breaks down and, in so doing, releases energy which the animal in turn, diverts to its own use for the creation of heat, the building up of its own body and the doing of work. The food which an animal eats not only supplies it with materials out of which to build or repair its body but also supplies the energy required to do the work and to perform other functions essential to its own well-being.

The green plant, on the other hand, employs an entirely different method of obtaining its food and energy. Its primitive ancestors learned to produce a material, leaf green or chlorophyll, which has marvelous properties. By exposing this chlorophyll to sunlight, the plant can employ the radiant energy coming from the sun to manufacture a food out of two of the most common and widely distributed compounds in nature—carbon dioxide and water. It forces these two simple compounds together into a more complex compound and, in so doing, causes work to be done and energy to be stored up. Thus, without appreciable effort on its own part, the green plant obtains its one and only energy-yielding food. This food is sugar.

Having produced sugar, the plant uses this food very much as the animal does the food which it obtains at the expense of other organisms. The plant builds up and adds to its own living substance by combining sugar with the elements nitrogen, sulphur, phosphorus, calcium, magnesium, potassium and iron, all of which it obtains in solution in the water in its environment. All the energy expended in the fabrication of living substance out of these non-living materials is obtained by breaking down or "burning up" some sugar. All the organic compounds incorporated in plant bodies such as cellulose, starch, oils, etc., which are not actual parts of their living substance but which, nevertheless, play very important roles in the economy of plants, are made out of sugar.

A little farther on, we shall discuss the manipulation of sugar by plants and note some of the many compounds which they make out of it; so, at this point, we shall only say that sugar is not only the energy-yielding food of the green plant but is also the chief building material out of which it constructs the living and non-living parts of its body. Sugar supplies the carbon for absolutely all of the organic compounds of plant origin.

PLANTS, ANIMALS AND SAPROBIA

The production of sugar through the employment of chlorophyll as a sunlight power plant is the most important invention that has been achieved by living things throughout the many millions of years that they have been dwelling upon the earth.

This epoch-making invention has been appropriately named "photosynthesis." It at once made available to its inventors an abundant supply of energy and unlimited possibilities for experimentation in the development of bodies or organisms of varying sizes and complexities in which this art of sugar manufacture could be carried on. This type of nutrition was adopted and used exclusively by a great group of organisms, the present day progeny of which we now speak of collectively as the Plant Kingdom.

Photosynthesis, the manufacture of an energy-yielding food out of carbon dioxide and water by means of chlorophyll, was the dominant factor in determining the line along which plants would develop and the types of bodies which they would build up. A plant simply has to pick a location where it can get sunlight, and water charged with carbon dioxide and the appropriate minerals and then remain stationary, and its food supply is assured. It does not have to move around in search of food. It merely sits still in an appropriate location and its food comes to it; as a result, plants are characteristically stationary organisms for, like all other living things, they are wont to follow the lines of least resistance.

Now, among primitive organisms there were some which learned a trick quite different from photosynthesis. It cannot properly be termed an invention, but should rather be designated a vice which became a vicious habit. These tricksters learned that they could gain a lot of energy for themselves very quickly by seizing and digesting the body of another organism, thereby gaining in a few moments all the energy that the other organism had accumulated in its lifetime. This heinous idea became the dominant ambition of a group of organisms and, in developing the idea and experimenting in the production of structures or bodies designed to carry it out, the great variety and complexity of organisms which we speak of collectively as the Animal Kingdom appeared on earth. Animals prey upon their neighbors, gaining all of their body-building material as well as their energy by this method.

As plants are plants because of the type of nutrition which they adopted, so animals are animals because of the type of nutrition which they adopted. They seize and appropriate to their own use complex compounds created by other organisms. An animal must go after its food. If it sits down and waits for it, it does not get much and is, as a result, a pretty poor animal. Locomotion is, therefore, a most essential quality in an animal. It enables it to pursue and overtake its food and it enables it to get away and avoid becoming food for some other animal. So, motility has always been a mark of perfection in animal development and animals have tended to specialize in this line. Motility has been one of the most important influences determining the types or kinds of bodies which animals would develop. There was, of necessity, a forward moving end which soon became a recognizable head. In this area were located the sense organs which enabled the animal to locate its food supply and distinguish between good and bad food; also, the mouth with which to seize its food.

Now, in contrasting plants and animals, we see that plants are plants because of the type of nutrition which they adopted and this has caused them to develop as stationary organisms and build bodies in which they can carry on to best advantage their type of nutrition. Animals are, on the other hand, characteristically motile organisms because of the type of nutrition which they adopted. They expend enormous amounts of energy in the constant activities of the mechanisms which they build up as bodies.

Plants are organisms in which constructive chemical processes predominate. They create new compounds more rapidly than they use them. Animals are organisms in which destructive chemical processes predominate: they destroy existing compounds far in excess of those which they build up and retain in their own bodies. Now this contrasting of plant and animal nutrition may seem to be a matter of passing interest only. We shall find, however, that it is a matter of great importance when we come to weigh the relative economy of growing plants or animals as food for human consumption.

To lay a complete foundation for our future food researches, we should also introduce at this time a consideration of the third great group or kingdom of organisms, the development and character of which were determined by the type or method of nutrition which they adopted. In a world of plants and animals, there was bound to appear vast masses of non-living organic matter resulting from the deaths of organisms because of old age, climatic changes, catastrophies, accidents and violence. Animals, as a rule, extract only a part of the nourishment from the food which they eat and usually consume only portions of the organisms which they kill. Plants shed their branches, leaves, flowers and other organs when these are no longer useful to them. As a result of natural processes, dead organic matter would rapidly accumulate on earth and in time reach enormous dimensions. This dead organic matter represents food and energy available to any organism that might wish to use it and can employ methods of handling it. As might well be expected, certain organisms coming in contact with this abundance of non-living organic products developed methods for obtaining the materials and energy necessary for their continued existence by attacking these products and extracting therefrom the nutrients which they required. These organisms assumed the role of scavengers, living on the dead bodies and castoff products of other organisms. Their nutrition somewhat resembles that of animals in that they live on products produced by other organisms, but these scavengers do not ingest or engulf solid food but apply portions of their bodies to the solids which they digest at points of contact and then absorb into their own substance only such portions as they can use. All organisms employing this type of nutrition may be spoken of collectively as the saprobia, which term, being interpreted, means rotten life or rotten living. While numerous organisms from the higher groups of animals and plants have fallen for this easy way of obtaining food, the best known, and to us the most important, saprobiacs are the bacteria and fungi.

These organisms, world-wide in distribution, perform many operations most essential to the maintenance of a proper balance in nature. They bring about the putrefaction and decay of organic materials, thus reducing these to fertile soil. They cause the fermentation yielding alcohol and, in a similar manner, produce acetic, lactic and other important acids. They are responsible for the curing of tobacco, the making of vinegar and many other processes which man encourages to his own advantage.

The majority of the bacteria and fungi have been content to remain scavengers, but a few, having learned what they want for food and where it comes from, attack the living organisms producing it and injure or destroy their tissues in order to supply their own needs. These vicious forms which we designate "parasites" are responsible for most of the infectious and contagious diseases to which plants and animals are subject.

SUGAR—THE FOUNDATION OF ALL FOODS

The first product of photosynthesis is a simple sugar made by forcing together into a single molecule six molecules of carbon dioxide and six molecules of water with the liberation of six atoms of oxygen.

Now, plants make two types or kinds of simple sugar, the molecules of which contain exactly the same number of atoms of carbon, hydrogen and oxygen, but with these atoms put together in different patterns. These two types of simple sugar differ from each other much as your right hand differs from your left hand—both hands have the same number of digits but the digits are not identically arranged—one hand being the mirror image of the other.

The two kinds of simple sugar are known as dextrose and levulose, also as glucose and fructose and, in simpler language, as grape sugar and fruit sugar.

dextrose = glucose = grape sugar
levulose = fructose = fruit sugar

Plants can convert dextrose into levulose and levulose into dextrose, the change back and forth being accomplished with no loss of sugar—just as a glove for the right hand, when turned inside out, becomes a glove for the left hand.

By combining or condensing varying numbers of molecules of dextrose into a single large molecule, many plants make multiple sugars each of which has specific properties. Certain plants also, in a similar manner, make multiple sugars out of levulose and numerous plants combine dextrose and levulose in equal amounts to make sucrose or cane sugar, which is our common table sugar. One of the most important multiple sugars is starch which is made by combining a number of glucose molecules from each of which one molecule of water has been extracted.

Many plants find it convenient to transform glucose into starch for storage purposes because starch is insoluble in water, while glucose is very soluble and readily diffusible through cell walls and, consequently, not so easily retained in tissues. Plants which employ starch for storage purposes convert it back into glucose when they wish to move it about in their bodies or to use it for food.

Another important multiple sugar made by all green plants is cellulose, which has the same chemical formula as starch but, because of the organization of its molecule, differs materially from starch with respect to properties. Cellulose is the building material out of which the solid parts of the plant body are molded. It is the primary and chief constituent of all woods. Plants are unable to convert cellulose back into glucose and animals are unable to digest it. Many of the saprobiacs, however, and particularly the wood-destroying fungi, make cellulose their chief food from which they derive organic materials for building their own substance and energy for doing the building. Some animals, by cultivating cellulose-digesting bacteria in their alimentary canals, are able to derive nutrients and energy from cellulose.

The simple and multiple sugars all contain hydrogen and oxygen in the same proportion as these elements occur in water and, as they are composed of carbon and water, they are spoken of collectively as carbohydrates.

Living substance or protoplasm we have found is a compound or complex of compounds in which ten or more elements are incorporated. Among these elements, nitrogen plays a most important and influential part and the organic complexes in which it is involved through the activity of protoplasm are known as proteins. Plants employing sugar as a source of carbon and energy can take up inorganic nitrogen and combine it with other elements to make protein. Many saprobiacs also have the ability to fabricate protein out of inorganic nitrogen and carbohydrates. The protoplasm of animals, however, does not possess this ability, but must get the nitrogen for its protein from proteins made by plants, by saprobiacs or by other animals.

The fats, which are extremely complex compounds composed of carbon, hydrogen and oxygen, play an important role in the vital economy of both plants and animals. Fats are made out of carbohydrates or out of materials derived from carbohydrates by the protoplasm of both plants and animals. In the making of a fat, the equivalent of numerous molecules of sugar are condensed into a single, large molecule with the elimination of considerable oxygen. Fat is a concentrated food and is employed for the storage of energy by both plants and animals. Plants make all of their own fats out of sugar but animals, feeding upon other organisms, make use of the fats as well as of the carbohydrates and proteins of their victims.

We are now in position to discuss briefly the sources of human food and the economics of its production. The essential constituents of food for a normal human being are carbohydrates, proteins, fats, vitamins and minerals. It is customary, however, to prescribe a human diet in carbohydrates, proteins and fats only, for the raw materials selected to supply these three major ingredients should also carry adequate supplies of vitamins and minerals, these latter being required in comparatively small quantities. It is also customary to measure the value of a food in terms of its fuel or caloric value, the unit being the calorie. Giving due consideration to the foods man is accustomed to eating, dietitians tell us that in the properly balanced diet of an adult human being, carbohydrates should supply about 65 per cent of the total caloric value; proteins, around 10 per cent; and fats, the remaining 25 per cent.

Carbohydrates, we have found, include simple and multiple sugars. Simple sugars, when taken as food, are absorbed directly into the blood, there to become immediately available as a source of energy. All multiple sugars, however, must be hydrolyzed or reduced to simple sugars in the process of digestion, for it is only when they are in the form of simple sugars that they can be utilized by the human system.

Sucrose or cane sugar is easily reduced to glucose and fructose, while starch is reduced to glucose with somewhat less alacrity. The fallacy of the oft-repeated statement that starch is less fattening than sugar should be readily apparent, for starch is reduced to sugar in the body before it can be utilized. When you eat starch, you are supplying your body with sugar.

Man still ingests the major portion of his carbohydrate food in the form of starch. This is undoubtedly due to the fact that starchy foods such as wheat, rice, corn and potatoes have in the past been more readily available to him than plant products containing sugar. With sugar now obtainable at a very low cost, he might well eat more sugar and thereby reduce the strain imposed upon his digestive system.

Man can obtain all of the protein which he needs from plants alone or from animals alone. This is readily understood, for, in the last analysis, all animal proteins are derived from plant proteins. As a rule, man prefers to so arrange his diet that he gets some proteins from animals and some from plants. Man does not convert the protein taken as food directly into the proteins of his own body, but must first digest these food proteins into simpler nitrogenous compounds which can be absorbed into, and transported by, the blood. These simpler compounds may then be extracted from the blood by the protoplasm at any point in the body and used to build new proteins. There is no substitute for proteins in man's diet. These compounds are the only source from which he can obtain nitrogen, and nitrogen, as we have already found, is a most essential element for the building and repairing of protoplasm.

Fats in the human diet are equivalent to concentrated carbohydrates for, like carbohydrates, they supply energy, but much more of it per unit of weight. A pound of fat will yield more than twice as many calories as will a pound of sugar. Some animals flourish on carbohydrates without the addition of an appreciable amount of fat, but man has become so accustomed to including in his diet fats produced by other organisms that he is unhappy if deprived of them. It would be quite possible, however, for him to supply his total requirements in materials and energy with carbohydrates alone; no part of his food need be in the more concentrated form of fats. Since one pound of fat in the diet is equivalent to somewhat more than two pounds of carbohydrate for the production of fat in the human body, it follows that a man can most readily control his weight by regulating his intake of fat. To get fat, he should eat fat and to reduce his weight, he should restrict his intake of fat. It should be obvious, therefore, that while sugar in the diet may help to make a person fat, it is apt to do so only when accompanied by plenty of fat.

An expert of the United States Department of Agriculture writes:

> "Fat is commonly thought of as a source of energy in the diet. A given weight of fat has more than twice the energy value of the same amount of carbohydrate or protein. Hence those who wish to reduce or to add weight should reduce or increase the fat content of the diet first."

It should now be obvious that all of the energy supplied by any food—be it carbohydrate, protein or fat—can be traced back to sugar. The cost of a food in nature's economy may be measured by the energy in that food plus the energy expended in its fabrication. Since sugar is the energy source for all foods, the cost of a food to nature should be measured in terms of sugar. To begin with, sugar produced by plants is in itself the most economical food, for it is the primary organic compound, the energy of which is derived directly and entirely from sunlight. The further a food is removed from sugar, the more energy has been expended in its production. Food products of plant origin are derived directly from sugar made by the plants which supply the products and, hence, a minimum of energy is consumed or expended in the transformation of sugar into these products. Food products from animals, however, represent an enormous expenditure of energy in their production for, as we have previously noted, animals are organisms in which destructive chemical processes predominate—they destroy, in existing compounds, many times the weight of the compounds which they build up and retain in their own bodies. Beef, for instance, furnishes us with protein and fat, but an animal supplying it consumes the equivalent of at least thirty pounds of sugar for every pound of beef which it yields upon slaughter. This means that fully 50 calories of energy derived from digestible plant products were expended by the animal for every calorie of energy which we obtain from its meat. To be sure, we are able to feed cattle on certain plant products that are not suitable for human consumption and, by so doing, recover a small amount of the energy which these products represent. This is a laudable procedure but when we feed to beef cattle products that are themselves suitable for human consumption, we are pursuing a most uneconomical course. Take yeast, for an example: should we use it for feed or for food? This prolific saprobiac thrives in a solution containing sugar and the more common inorganic salts. It feeds on the sugar and, picking up the necessary nitrogen and mineral elements, builds up new protoplasm, growing at a prodigious rate. The yeast organism does not construct a complicated body but merely clothes its living substance with a thin membrane. A mass of yeast, therefore, is little more than a mass of protoplasm and when we dry this mass, it is largely protein, for protoplasm, we have found, is essentially protein. When growing in a sugar solution, the yeast organism breaks down the sugar into alcohol and carbon dioxide and builds in its own body protein and fat, so the culture of yeast in a sugar solution yields three valuable food products—protein, alcohol and fat. Under favorable conditions, which are easily maintained in any climate, a crop of yeast grows to maturity in less than 24 hours, so it is quite possible to harvest a crop every day in the year. At a pilot plant in Honolulu, all the details of yeast production as a commercial crop have been worked out. The dry product is 50 per cent protein and very rich in the vitamins of the "B" complex. It is quite palatable and a number of people have for some time been eating it regularly to determine its value as a source of protein in the human diet. Their reactions are all very favorable. A few people, suffering from nutritional disorders, are also being supplied with this yeast and some of them report remarkably pleasing results. One man who had always been emaciated gained 20 pounds in a few months and thereafter maintained a normal weight. A diabetic, after eating yeast regularly for some time discovered that his tolerance for carbohydrates had greatly increased. He enjoyed this increased tolerance only so long as he included yeast in his diet. Naturally, he eats yeast regularly if he can get it.

Strange to say, this pilot plant is being promoted with the idea of producing yeast, not for food for human consumption, but for feed for livestock. Up to the present time, most of its output has been used in feeding experiments with cattle, hogs, poultry, etc. The results of these experiments, I am privileged to report, favor the use of yeast as a source of protein. However, since this yeast has proved to be a good protein food for humans, it is poor economy to feed it to beef cattle, for it will be necessary to feed at least 10 pounds of yeast protein for every pound of protein recovered in beef.

SUGAR—THE SOURCE OF ALL MOTOR FUEL

If all the animals on earth were separated from all of the plants and plant products on earth, the animals would very soon die and disappear from the face of the earth. Animals are absolutely dependent on plants for their food. Certain animals, it is true, prey almost entirely upon other animals and many animals subsist upon a mixed diet of animal and plant materials, but the great majority of animals eat plant material only as their food. Animals which become the food of other animals are, themselves, plant feeders or feed upon animals that are plant feeders. We might very possibly cite special cases where flesh-eating animals eat flesh-eating animals that eat flesh-eating animals in a sequence of considerable length, but this sequence would eventually end with an animal that fed exclusively upon plants. There is only one possible conclusion to our investigation along this line: all animals derive the energy with which they operate their bodily mechanisms directly or indirectly from plants. Traced to its ultimate source, it was energy locked up at one time in the bodies and products produced by plants and these, we have found, have their origin in sugar.

That the vast coal beds of the world are the residue or remains of plants which grew upon earth in bygone ages is too well known to require discussion here. There may be some grounds for debate as to whether the world's deposits of petroleum and natural gas were derived from animal or from plant remains or from a combination of animal and plant remains, but such questions need not concern us in our present thesis for, whatever the correct answers to these questions may be, we have already established the fact that all of the energy represented must have been accumulated in the first place by plants and they garnered it from sunshine and locked it up in sugar.

The facilities, comforts and conveniences of modern civilization are made possible by the extensive mechanized industries and transportation systems which man has built for himself. To operate these industries and systems, he is expending vast amounts of energy which he derives from coal, petroleum and natural gas. Now, these materials are the remains of organisms which lived upon the earth in bygone ages and the energy which they now yield reached the earth as radiant energy where it was captured by green plants and locked up, first as sugar, then later transformed into other organic products.

The deposits of coal, oil and gas, on which the perpetuation of our modern civilization so largely depends constitute inherited capital which is not being replenished. Its ultimate exhaustion is certain and too imminent for pleasant contemplation. When this inherited capital is gone, our only source of fuel will be products derived from current crops and the serious question is: how much fuel can current crops provide after they have supplied our food requirements?

To gain some knowledge of the problems which man must solve in order that his mechanized industries and transportation systems may continue, let us examine some of his present-day expenditures in energy-yielding products and the sources from which he draws them:

Petroleum is today our most important and most patronized source of energy, so we will examine the petroleum situation. There is now being extracted from this earth, each year, over 2 billion barrels of petroleum. Crude petroleum yields at least 1½ billion gram calories per barrel, so 2 billion barrels will represent 3 quintillion gram calories of energy. Now, a very generous estimate of the energy which might be recovered by man and converted to his own use from the organic compounds made by all the plants on earth during a single year would be 200 quadrillion gram calories. It follows, therefore, that when man consumes 2 billion barrels of petroleum in a year, he is expending at least fifteen times as much energy as he could recover from that captured by all of the plants on earth in that same year. The inevitable result of this prodigality is too obvious to require discussion.

Petroleum geologists, who have made a careful study of the situation, estimate that at the present rate of consumption the world's visible supply of petroleum will be exhausted in another twenty years while the most optimistic petroleum exploiters, after making due allowance for the new oil fields which they expect to discover, do not claim that the world's supply will last more than forty years. To us, the most appalling feature of this situation is the fact that the United States is now providing 60 per cent of the world's petroleum. It is dissipating one of its most valuable and most vitally important natural resources in a most stupid and reckless manner. By so doing, it is inviting, if not insuring, a national calamity of unprecedented proportions. Contemplate, if you will, the predicament of the United States when, its own petroleum supply exhausted, it has to buy oil from other countries. Under such conditions, where will we be in case of war? Should not the conservation of petroleum be made a national issue?

When the impending petroleum shortage is mentioned, it is often dismissed with the reassuring statement that: "when petroleum is gone, we will derive our liquid fuel from coal and oil shales of which we have large deposits." Quite true, we can obtain liquid fuel from these sources, but its energy will cost us many times the present price of that supplied by petroleum, as we shall have to expend much energy to bring about the conversion. The obvious result will be a very rapid consumption of our inherited capital in coal and oil shales, leading to their speedy exhaustion. Another oft-repeated assertion deserving our attention is that when gasoline is no longer available, or becomes too expensive, we will use alcohol instead. This sounds reasonable, for alcohol has proved to be an excellent substitute for gasoline in internal combustion engines. However, if America was deprived of gasoline today, alcohol could never be made available in the country in sufficient quantities to fill its place. Alcohol is derived from other organic compounds all of which must have had their origin in sugar. It represents radiant energy which was at some time captured by green plants. Through fermentation, we obtain alcohol from carbohydrates; by distillation, from wood; and by synthesis, from petroleum. The production of alcohol, therefore, necessitates the consumption of existing food or fuel and, consequently, does not in any way increase our available supply of energy. To be sure, it does afford us an opportunity to convert surplus food into a useful fuel, an opportunity which in this country is at the present time being criminally neglected.

Our nation annually consumes about 22 billion gallons of gasoline. If we took absolutely all of the fermentable crops produced in one year in the United States and converted them into alcohol, we should obtain far less than half of 22 billion gallons, and a gallon of alcohol has considerably less energy value than a gallon of gasoline.*

Now, we shall always require at least 80 per cent of our fermentable crops for food, hence, not more than 20 per cent will be available for alcohol production, so we can never expect to annually produce more than 2½ billion gallons of alcohol for fuel purposes from our surplus crops unless we radically modify our agricultural industry as to acreage, methods of culture and crops grown.

AMERICAN FARMING INDUSTRY STRANGLED BY UNFAIR COMPETITION

During the first half century of our nation's existence, the farmers of the country produced not only all of the plant food consumed by its human population but also supplied with their crops the energy which moved all conveyances overland within its boundaries. All passengers and all freight were moved by animals which derived their energy from feed provided by crops of the day. Shortly after our country had passed its fiftieth birthday, however, railroads began to displace animal-drawn conveyances over the most profitable routes and by the time our country had passed its seventy-fifth birthday, the railroads had captured a very large part of its freight and passenger traffic. The railroads expended vast amounts of energy to move their trains but they derived this energy from coal, not from the current products of the farm.

At the beginning of the present century, the farmers of the United States still supplied with their crops the energy that moved most of the freight of the country over at least a small part of its journey from its place of origin to the point at which it was consumed. The railroads and steamships made the long hauls, to be sure, but a very large part of their freight was hauled to and from the depots and wharves on animal-drawn trucks and drays. Likewise, transportation of all products from the farms and the distribution of all commodities within the cities were accomplished with horse-drawn carts and wagons. Coaches, hacks, cabs and buggies carried passengers over country roads and city streets. Horses and mules furnished all the motive power on the farms. In those days, millions of draft animals were used daily throughout the country and millions of acres of farm land were continuously employed for the growing of crops to feed these animals and supply the energy which they expended. During the past forty years, however, draft animals have been almost entirely replaced by internal combustion engines. All types of horse-drawn vehicles have disappeared from our city streets and now are rarely seen even on our country roads. The majority of our farmers have reduced their strings of horses and now use motor trucks and tractors on their farms.

Automobiles, buses, trucks and tractors are propelled by internal combustion engines and the energy operating these engines is derived from underground deposits of oil and gas and not from the crops of modern farms. As a result, millions of acres of land which, in 1900, produced crops to feed draft animals are now idle or contribute to an unwieldly surplus, and hosts of farmers' sons who should be gainfully employed cultivating these acres have been compelled to leave the farms and seek a livelihood elsewhere. The displacement of draft animals by internal combustion engines has accomplished the displacement of farm-grown feeds by petroleum products. The crops of today were made to compete with the crops of bygone ages. These ancient crops were raised, garnered and processed by nature without human assistance. Consequently, they carry no charges for taxes paid on the land on which they grew, no charges for labor expended in planting and harvesting, and no charges for concentration and storage. Petroleum and natural gas are removed from the earth at little expense and are sold at such ridiculously low prices that present-day plant crops cannot begin to compete with them as a source of energy.

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* From data prepared and published by experts in the U. S. Department of Agriculture (Miscellaneous Publication No. 327, page 43), we learn that: if all the fermentable crops, Apples, Apricots, Barley, Buckwheat, Carrots, Corn, Dates, Figs, Grain Sorghum, Grapes, Peaches, Pears, Plums, Potatoes, Sweet Potatoes (including Yams), Rice, Rye, Sorgo Sirup, Sugar Beets, Sugar Cane (for sugar), Sugar Cane (for sirup), Sugar Cane Molasses (black strap), and Wheat produced in the United States in the year 1935 had in their entirety been converted into anhydrous alcohol, the total yield would have been somewhat less than 9,631,000,000 gallons.

Clearly, the farming industry is the victim of the most unfair and devastating competition that any major industry has ever had to meet. The huge transportation-energy market, which at one time it alone supplied, has been invaded by the petroleum industry which, in a few short years, rendered farming unprofitable and drove millions of men away from the farms. Thus, the unrestricted exploitation of America's petroleum supply has not only wrecked the farming industry but has, at the same time, seriously disrupted the social and economic life of the country.

While the progressive destruction of the farming industry has been constantly apparent and the factor bringing about this destruction easily discerned, our national law makers have taken no effective steps to succor the farming industry by checking the unfair competition to which it was subjected by the petroleum industry.

There are many ways in which the two industries could be maintained upon an equal and fair basis, but the most logical method would be to require that all motor fuels sold within the United States contain a certain percentage of anhydrous alcohol. This percentage should be such as would require the conversion of all possible crop surpluses into alcohol in order to attain the necessary volume. It should be possible to raise this percentage to such a point that it would call for the intensive cultivation of millions of acres of land now idle or producing only a small part of their potential yield. It would also return many idle men to agricultural pursuits and to the handling and processing of farm products. It would go a long way towards curing our greatest national malady—unemployment—and finally it would be a most decisive and profitable step in the conservation of our natural resources.

While considering the plight of the American farmer and the unfair treatment accorded him by our government, we should call attention to the fact that two important products of American farms, alcoholic beverages and tobacco, are unmercifully taxed. Why should these products of modern farms be made to contribute so heavily to the support of government, while coal and petroleum, products of the untaxed and unworked farms of bygone ages be allowed to escape with light taxes?

WE SHOULD INCREASE OUR SUGAR PRODUCTION

In order that our children and our children's children may experience the blessings, comforts and conveniences which we now enjoy, there must be available to them an enormous amount of convertible energy. By our reckless consumption of coal, oil and gas, we are dissipating the world's reserves and thereby depriving posterity of its rightful share in this inheritance. Our interest in, and obligations to, posterity and to our country demand that we temper our consumption of coal, oil and gas by gathering with our current crops all of the radiant energy possible. Instead of restricting production on our farms, we should take effective steps to increase production. We should select for cultivation crops that yield a maximum of convertible energy. Instead of paying farmers a bonus for curtailing production, we should insure them adequate returns for maximum crops. There would never be a surplus under proper administration.

In selecting crops to be grown on American farms, we should first assign an adequate acreage to crops essential for food. Having done this, we should then select for cultivation in each locality the crop that, growing in that locality, will yield the largest amount of convertible energy per acre. In the following table we reproduce data supplied by the United States Department of Agriculture on which such an allotment might well be made.

AVERAGE YIELD OF 99.5 PER CENT ALCOHOL PER ACRE

Material	Gallons	Material	Gallons
Sugar cane (Hawaii)	444.5	Pineapples	78.0
Sugar beets	287.0	Rice, rough	65.6
Sugar cane (Louisiana)	268.0	Pears	49.3
Jerusalem artichokes	180.0	Barley	47.9
Potatoes	178.0	Apricots	41.0
Sweet potatoes	141.0	Oats	36.3
Apples	140.0	Grain sorghum	35.5
Dates, dry	126.0	Buckwheat	34.2
Carrots	121.0	Wheat (all varieties)	33.0
Raisins	101.7	Figs, fresh	31.5
Yams	94.0	Figs, dry	29.5
Grapes (all varieties)	90.4	Sorghum cane	26.4
Corn	88.8	Rye	23.8
Peaches	84.0	Plums (non-prunes)	21.8
Prunes, dry	82.8		

A glance at this table will convince anybody that every acre in the United States which will grow sugar beets or sugar cane should be devoted to these crops, for they lead all others in yields of convertible energy per acre.

WE MIGHT STORE SUGAR INSTEAD OF GOLD

It is most certainly true that the world's population is now consuming each year in food and fuel, many times as much energy as is being accumulated on earth by its crops during that same year. If this is allowed to continue, consider the plight of man when the supplies of petroleum and coal are exhausted. He may be able to feed himself but he will have no great surplus of organic materials to convert into fuel and it will be too late to build up a supply for this purpose. It would only be reasonable foresight, therefore, for the present-day nations to store up organic compounds against that time in the not-distant future when they will be sorely needed.

The United States already has a very large part of the world's available gold stored in its strong chambers. If, now, other nations should pay their outstanding debts to the United States in gold, this country would soon have in its possession practically all of the world's mobile supply of this precious metal. When this condition had been arrived at, it would then be possible for all other nations to forbid the circulation of gold, much as our own country has done, and the United States would find that its once precious metal had become an almost useless metal for, in case of an emergency such as war or famine, its gold could not be converted into food, fuel or even good ammunition.

Now, supposing that instead of storing only gold, we should store some sugar. Then, in case of an emergency, our sugar reserve would supply us with food of the highest quality, efficient fuel and even high explosives. The sugar itself would be the very best carbohydrate for human consumption and by feeding some of it to yeast, we could obtain an excellent protein and some fat to round out our food requirements, at the same time recovering alcohol for liquid fuel. Pure sugar, if properly stored, will keep indefinitely and we need not fear that we might accumulate too large a reserve for, when the world's supply of petroleum is exhausted, the demands for sugar will be far in excess of any supply that it will have been possible to accumulate in the world before this crisis overtakes it.

While the storage of vast amounts of sugar is feasible, it would be far better economy to convert each year all sugar not needed for food into fuel alcohol and arrange for the immediate consumption of this alcohol in place of its equivalent in gasoline. Petroleum is already safely stored in underground reservoirs provided free by nature and we should take steps to retain a supply in these reservoirs just as long as possible.

SUMMARY

All plants, gathering energy from sunlight, manufacture out of carbon dioxide and water their one and only energy-yielding food—SUGAR.

All animals and all saprobia derive their energy-yielding food directly or indirectly from plants and consequently from sugar.

All of the energy which we obtain from coal, oil and gas was accumulated in the very remote past by plants and they garnered it from sunshine and locked it up in sugar.

Agriculture, the cultivation of plants for the production of sugar and compounds made therefrom, is the very foundation on which civilization has been built.

Petroleum products, derived from the untended and untaxed crops of bygone ages, have displaced the products of modern farms in the transportation-energy market and by so doing all but wrecked American agriculture.

Civilization of today is squandering the latent energy inherited from the past in a most heedless and reckless manner; drunk with cheap power, it is fast riding to a fall.

Our obligations to our country and to posterity demand that, each and every year, we gather with our crops all of the radiant energy possible.

Sugar beets and sugar cane are far superior to all other crops in ability to gather radiant energy and render it available to man in food and fuel.

In closing we wish to say that all of the data presented in this thesis may be found in current publications and more particularly in those issued by the United States Department of Agriculture.

All of this information has long been at the disposal of our National Government yet, in recent years, it has enforced a curtailment of our crops, thus preventing the acquisition of large amounts of energy which we might have garnered with these crops and added to our resources but now have lost forever.

Internal Moisture Relations of Sugar Cane—The Selection of a Moisture Index*

By HARRY F. CLEMENTS and T. KUBOTA

In attempting to arrive at a proper approach to an irrigation program, two general avenues are open. One involves an effort to evaluate all of the factors which affect the transpirational requirements of a given crop consisting of soil, atmosphere, and plant factors. A program based on such a multitude of factors, many of which necessarily are unknown, seems destined for such involved complications as to render it impractical. The second, proposed earlier by the senior author, is based on the simple hypothesis that the moisture level of a crop at any one time is the result of the interplay of all internal and external factors affecting the water relations of the plant as integrated by the plant itself. *In this, all of the difficult and complicated calculations involved in the first approach are automatically taken care of by the plant. To use this method requires a tissue to be known as a Moisture Index which can be collected periodically and its moisture level determined. By associating the various levels of the Moisture Index with the physiological behavior of the plant, the grower will be able to provide water as needed by the crop.*

Data obtained from eight plots of sugar cane, four of which were grown at Waipio and four at Kailua, were examined for a suitable Moisture Index. The organ selected is made up of the sheaths of the elongating cane leaves. Satisfactory correlations were found between the moisture content of this organ and the active growing tissue, the whole of the green top of the plant, as well as the millable cane. Curves and straight lines were constructed for these relationships and their predictive values determined.

INTRODUCTION

Curiously enough, water, which makes up the greatest part of a plant, has received far less attention from students of growth processes than have such materials as specific growth substances which occur in the merest of traces. Most of the attention of research workers concerned with moisture relations has been directed toward the relation of water to soil (2), the nature and availability of water in soil (21), cultural practices designed to reduce water loss both through evaporation and runoff. Only casually has the plant received attention, and this essentially has been directed toward such empirical results as the wilting of plants in relation to soil moisture, and yields obtained in relation to irrigation frequency and amount. Some effort has been directed toward the selection of crops or varieties with low transpirational requirements.

Until recently practically nothing has been done to understand the positive effects of transpiration (5) nor have the internal moisture relations of plants received objective attention. Too many investigators have subscribed to the quaint

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view, even recently urged, that transpiration is essentially a harmful process (12), little realizing that it is necessarily the process which on the one hand augments the absorption (13) and translocation of materials (8) essential to the physiological reactions of terrestrial plants, and on the other hand enables the plant to safely project itself into a high energy environment (23) so finally necessary to rapid synthesis and growth (9, 17).

It should be obvious to any observer that in regions where moisture in a soil is less than sufficient for the growth of a given crop, it superficially appears as though transpiration is the cause of the failure of the crop. Actually, however, the direct cause of the failure is the selection of a crop which morphologically and physiologically is adapted to an environment either of lower energy levels or higher moisture levels or both. On the other hand, plants which are so adapted to grow in a high-energy atmosphere with adequate water are as likely to fail in normal growth when transferred to a low energy-high moisture area, but the failure here is due to excessive hydration. It should never be forgotten that plants which are grown as crops usually would not, if left alone, select the particular field as the place to become established. It is common experience that fields which are abandoned are soon invaded first by weeds and then later by the native plants from the fence row.

Fortunately, the habits and requirements of a species are not inflexible, but when the extreme of flexibility is attained, either the environment must be changed or the plant will fail to grow successfully. Such failure is clearly traceable not to a single plant process but rather to the general incompatibility existent between the particular physiological entity and the environment. Under such circumstances selection of new agronomic varieties of the species may result in a better adjustment.

Where plants are grown in greenhouses, it is possible to provide a species with a close replica of its natural environment. The most successful greenhouse growers are those who come closest to fitting the total plant environment to the particular physiological complex which they are hoping to produce. Outside of controlling temperature and in part sunlight, practically all the growers' attention is directed toward the proper manipulation of moisture relations. "Watering" in greenhouses is an art, the practice of which requires the most competent and observing men. The application of fertilizers is secondary in importance. That is, sufficient nutrients are provided to avoid less than adequate amounts, but above this threshold, the grower regulates the behavior of his plants by proper applications of water. The interval between applications varies from day to day, depending on cloudiness, temperature, and stage of plant growth. During the early vegetative phases of the plant cycle, other things being equal, the interval is shorter than it is later on toward the "storage" and reproductive phases. In other words, the vegetative growth of plants is pushed or forced by frequent "waterings" and checked by less frequent "waterings."

Furthermore, the nature of the internal processes of a plant growing under field conditions favoring high moisture content of tissue differ in types as well as intensities from those of plants which have entered into a drought reaction. Associated with the former is a high metabolic rate, rapid growth, rapid transpiration, rapid absorption and translocation of soil solutes, succulence of tissue, in many plants a failure to develop a root system in proportion to the top (3), rapid expansion of the leaf area (9), and a high degree of carbohydrate utilization sometimes including various degrees of depletion of reserves previously deposited (6, 7). Coupled with these high-speed reactions are dangers against which the plant is poorly prepared. Such plants are easily battered and broken by winds. The exposed succulent tissues serve as an easy corridor of infection for rot-causing organisms. Plants with poorly developed root systems are ready victims for severe atmospheric droughts. Finally, in sugar cane, when plants in this state are harvested, even though the tonnage may be phenomenal, the water content is so high and the sugar content so low that sugar yields are distressingly poor.

On the other hand, when plants which are capable of undergoing the drought reaction are subjected to a gradual atmospheric drought or soil drought or both, they react very precisely. Metabolic processes are reduced in intensities and are even changed in nature (19, 4). Total transpiration, and even unit transpiration is reduced (14, 18), root systems are extended (3), leaf area is sharply reduced (9, 11), leaf color changes from a dark green to yellow green, cell walls become thick and hard (6), and carbohydrate reserves begin to accumulate (4). Paralleling these changes, the plant becomes less susceptible to damage by wind or sudden and severe atmospheric droughts (7). Further, when sugar cane is harvested following such hardening, even though the total plant tonnage may be lower than average, the sugar yield is relatively high.

It is cogent now to examine the feasibility of controlling sugar cane growth in Hawaii. As has already been pointed out, in greenhouses everywhere plant growth is in large part controlled by intelligent application of water. Here in Hawaii the climate is essentially a "greenhouse climate." Furthermore, of the total acreage given over to sugar cane, somewhat more than half is under partial or complete irrigation. It therefore appears, that we have here an opportunity to grow an eighth of a million acres of sugar cane using much the same precision that is used on a very few plants grown under glass. For those areas in which rainfall is a direct source of water, and especially in those areas where the rainfall is excessive, physiological methods of reducing moisture levels within the plant may be helpful.

Although it is possible for the cane grower to learn a great deal from greenhouse practice, many factors are introduced which of necessity must be considered in arriving at a proper irrigation program. Thus, in greenhouses control of relative humidity, air movement, and temperature can be mechanically effected. Soils are mixed so as to result in adequate aeration, drainage and fertility. Some of these factors may be controlled but others are outside the control of the cane grower. That the depth and nature of the soil permeated by the roots of the plant are of primary importance need not be argued, yet, the chief loss of water held by a soil planted to sugar cane is through transpiration. Thus, the factors which are involved in determining the irrigation interval are multiple and complex. On the one hand, the volume of water in the soil about the roots is the reservoir from which the plant obtains the moisture for its needs. If the soil is shallow, irrigations will need to be more frequent than if the root-permeated zone is deep. But within the limits of the soil's capacity to hold a quantity of available water, atmospheric and plant factors become the most important. These factors are numerous and diverse. The distribution and vitality (15) of the roots, the age of the crop, the leaf area of the plant, the density of the stand, the normal transpirational idiosyncracies of the particular variety are plant factors which must figure in the nature of the irrigation program. Temperature, the intensity of sunlight, relative humidity and air movement are atmospheric factors all of which play a large part in determining the transpirational losses. Finally, it should not be forgotten that the plant may under certain conditions of unbalance between internal pressures and external conditions of temperature and humidity actually absorb water from the atmosphere (1, 16, 22).

There are two general approaches to an irrigation program. One involves the application of water at intervals, the length of which is determined in part by rule-of-thumb methods obtained through experience, and in part through criteria based upon soil and/or days or number of degrees of temperature* a crop has experienced (20). In the average year such a program generally fits well with the actual needs of the plant. But when one remembers all of the factors involved in determining the water requirements of a crop, it is apparent that any program imposed upon it which would consider all the factors in their proper proportions would be hopelessly complicated and detailed. Further, it is a rare year that is average.

The second approach to an irrigation program (9) is based upon the simple hypothesis that the moisture level of a crop at any one time is the result of the interplay of all the internal and external factors affecting the water relations of the plant as integrated by the plant itself. Thus, if it were possible to determine the moisture level of a crop under field conditions and through experimentation determine the growth behavior of the crop to particular moisture levels, it would be fairly easy to provide the necessary amount of water month by month throughout the growth cycle. This method is now being used in the experiments to be described presently, superimposed upon the day-degree method of Swezey and Denison.†

It is the purpose of this paper to report studies which have been under way for the past three and a half years. These studies have in part been directed toward an analysis of the moisture levels within the various tissues or organs of the sugar cane plant to determine their interrelationships and to obtain from these studies a tissue or organ which can be used as an "index" to the general moisture relations of the plant. In a later communication, an attempt will be made to associate the various moisture levels with the growth reactions of the plant.

It is hoped that once such a moisture index is located and adopted, it will be used extensively on the plantations where careful records will be compiled so that as time goes on we shall accumulate a background of precise information against which modifications of practices will become apparent. With this objective, it is clear that a desirable index tissue is one which is precise and at the same time readily available to the sample collector. Further, it must in its moisture variations reflect the moisture levels, not only of the growing, meristematic tissues, but also those of the mature portions of the plants.

EXPERIMENTAL

Sugar cane variety 31–1389 was used in these studies.‡ Plantings were made

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*** Swezey, J. A., and Denison, F. D.—local citation.**

† Local citation.

‡ Although the numerical values obtained in these studies may not be correct for other varieties, there is no reason to believe that the relationships will not hold.

at the Waipio substation and on the uplands at Kailua on Oahu. The first plots (.25–.33 acre) at each place were planted July 28, 1938 with cane pieces selected from one field at Waipio. These first plots are called Waipio Plot A and Kailua Plot A, respectively. Plots B were planted October 28, 1938, Plots C, January 28, 1939, and Plots D, April 28, 1939. Thus, planting each series at three-month intervals should introduce the influences of time of planting on subsequent behavior. Further, the series at Waipio is in a climate of high light intensity and complete irrigation while that at Kailua is in a cloudy region where no irrigation is practiced. The rainfall for the plant crop was adequate, although most of it fell during the winter months with a short drought developing during the summer months. The actual amounts of water applied are of no moment to this paper, however, since it is concerned chiefly with internal moisture relations of the plant.

Beginning about two months after planting and continuing at intervals of about one month throughout the remainder of the 22-month-crop cycle, in the early morning hours (5:45 to 7:00 a.m.) five carefully selected plants from each plot were removed from the field and separated into their several parts as already described in previous papers (9, 10). These samples were tightly wrapped in paper or placed in large screw-capped bottles and then taken to the laboratory where the weights of the fresh tissue were recorded. The material was minced, placed on screen trays which were then placed in a drying cabinet heated to 90° C. through which a strong blast of air was forced. This temperature is safe so long as the air blast is maintained. The leaf and sheath material as well as the elongating cane and meristematic material is completely dry in from 2 to 3 hours, although more time is required for the cane samples (up to 8 to 12 hours). The dried samples were again weighed, and the moisture percentage based on the green weight was then calculated.

Data and Discussion

Although the data from the collections of all plots are used in the subsequent analyses, it seems unnecessary to record all of the data here. In order to give the reader an idea of the actual percentages obtained, the results are given for only two of the plots—Waipio Plot B (Table I), and Kailua Plot B (Table II). These tables reveal two important facts: (1) Each type of tissue or organ has its own characteristic moisture level even though it is directly attached to another tissue of a very different moisture level. For example, the elongating cane blades maintain a moisture level around a mean which is between 10 and 15 percentage points lower than that of the associated sheaths. The sheaths in turn have a considerably lower moisture level than the elongating cane to which they are attached; (2) In any given tissue or organ, the range in moisture level between conditions of extreme drought and extreme wetness is comparatively narrow. Thus, in Table I, the collection made July 26, 1940 was from a completely dried out crop ready for harvest, while that collected October 27, 1939 was taken after a period of heavy irrigations as well as rainfall, yet the range of moisture level in each tissue or organ is for the most part within 10 percentage points. It is apparent from these observations that considerable precision will be possible in considering influences of moisture levels upon the behavior of the plant.

That moisture levels of a plant are intimately associated with the growth of the

TABLE I
MOISTURE CONTENT OF PLANT PARTS—WAIPIO PLOT B
(% Green Weight)

	1939											1940					
	Feb. 13	Mar. 23	Apr. 20	May 25	June 26	July 22	Sept. 1	Sept. 29	Oct. 27	Nov. 25	Dec. 26	Feb. 1	Mar. 8	Apr. 12	May 17	June 21	July 26
Meristematic material	92.9	91.5	93.3	93.8	92.4	92.7	91.5	93.5	92.3	92.6	89.7	91.7	90.6	91.1	91.6	84.5	86.4
Spindle cluster	82.7	79.6	81.9	81.4	80.5	81.1	77.7	80.5	80.4	78.8	78.2	79.3	79.1	77.3	77.2	72.5	73.9
Elongating cane—blades	75.9	75.0	73.2	74.0	73.1	72.9	69.7	71.4	71.9	70.9	72.6	72.6	68.7	69.7	68.1	67.1	67.4
Elongating cane—sheaths	87.3	84.7	84.6	85.0	85.0	85.1	82.7	86.2	85.7	83.4	83.6	85.8	80.0	80.2	79.6	76.2	73.1
Green-leaf cane—blades	75.8	75.8	76.5	72.9	72.1	71.9	66.0	68.1	68.2	68.5	70.4	70.7	66.5	66.7	65.9	67.2	67.5
Green-leaf cane—sheaths	87.5	84.1	83.0	81.7	81.0	81.2	77.6	80.4	82.7	79.0	80.8	81.6	78.3	76.8	75.5	73.9	75.9
Elongating cane	92.9	91.9	92.4	93.0	91.8	92.2	91.0	93.0	92.1	90.7	89.7	89.6	89.4	89.3	90.0	84.4	87.7
Green-leaf cane	89.6	87.9	90.8	88.1	86.7	87.7	84.4	87.9	86.4	83.5	82.1	84.0	80.3	81.3	83.6	80.9	83.6
Top internodes				81.3	79.8	80.9	80.0	82.4	80.0	77.6	77.2	77.2	73.4	73.2	77.6	73.8	74.9
16th—3 internodes																	73.7
15th—3 internodes																	72.9
14th—3 internodes															73.5	72.4	71.8
13th—3 internodes															71.3	70.9	71.3
12th—3 internodes															70.9	71.3	72.1
11th—3 internodes														74.7	71.8	69.5	72.5
10th—3 internodes												75.8	72.9	72.6	71.9	72.4	72.6
9th—3 internodes												75.4	72.7	72.5	71.6	72.8	72.8
8th—3 internodes												74.3	72.3	72.1	71.7	71.8	72.3
7th—3 internodes									79.5	75.6	75.3	74.2	72.0	69.8	70.9	70.9	70.9
6th—3 internodes								80.2	79.1	74.9	74.6	73.5	71.5	70.8	70.4	69.6	69.8
5th—3 internodes							79.9	79.9	77.8	74.5	74.1	73.5	71.1	69.6	70.8	68.8	69.8
4th—3 internodes						79.8	78.1	78.3	77.2	73.9	73.7	74.1	69.4	69.9	69.4	68.5	69.0
3rd—3 internodes						77.5	77.0	77.7	75.3	73.0	73.9	72.9	70.7	69.6	69.4	68.4	68.9
2nd—3 internodes					77.7	76.2	75.9	76.1	76.2	72.3	72.9	72.1	70.2	69.4	69.1	68.1	68.0
1st—3 internodes			81.1	77.2	74.8	74.8	74.4	74.5	74.7	71.4	72.2	70.7	69.9	68.6	68.0	67.2	67.8

TABLE II
MOISTURE CONTENT OF PLANT PARTS—KAILUA PLOT B
(% Green Weight)

	1939											1940					
	Feb. 15	Mar. 24	Apr. 21	May 26	June 27	July 23	Sept. 2	Sept. 30	Oct. 28	Nov. 24	Dec. 27	Feb. 2	Mar. 9	Apr. 13	May 18	June 22	July 27
Meristematic material	94.7	92.8	93.8	92.0	93.0	92.4	90.9	92.8	93.2	92.5	93.3	92.2	90.8	92.7	93.2	92.9	87.5
Spindle cluster	81.5	79.9	80.5	79.8	79.8	79.8	76.0	80.9	81.4	80.3	79.6	79.5	78.8	80.3	80.9	78.8	72.7
Elongating cane—blades	79.2	77.0	74.0	73.5	71.9	72.2	69.9	70.9	72.9	74.0	73.5	74.1	72.9	73.7	73.6	71.6	70.7
Elongating cane—sheaths	89.0	85.7	84.8	83.3	81.8	83.0	79.9	83.5	84.4	84.8	84.4	84.0	80.1	83.1	83.3	80.7	77.4
Green-leaf cane—blades	79.0	76.5	74.3	74.2	73.6	73.4	69.6	67.6	70.1	69.9	72.5	73.9	70.5	73.1	72.5	70.7	71.7
Green-leaf cane—sheaths	86.3	84.3	82.4	82.3	80.4	80.4	77.5	77.6	80.5	79.5	80.5	80.4	79.8	80.7	79.2	78.0	76.8
Elongating cane	92.0	91.5	91.7	91.8	92.0	91.3	89.7	92.2	92.0	91.5	90.9	89.6	88.7	91.3	91.4	89.9	87.0
Green-leaf cane	87.8	85.7	87.3	86.7	85.5	84.7	80.2	84.8	86.9	85.9	83.0	81.6	81.4	83.8	85.6	84.5	81.6
Top internodes				79.4	77.2		74.8	76.0	77.8	79.6		76.5	75.3	73.4	76.0	74.0	76.6
15th—3 internodes																	75.8
14th—3 internodes																	73.6
13th—3 internodes																	73.6
12th—3 internodes																74.0	71.3
11th—3 internodes															75.1	74.0	69.9
10th—3 internodes															73.9	72.7	69.8
9th—3 internodes														73.7	74.6	71.7	70.2
8th—3 internodes												76.3	74.3	73.7	73.9	71.5	70.7
7th—3 internodes										77.3	77.7	75.1	73.5	73.0	72.8	71.8	71.8
6th—3 internodes									75.6	75.8	76.6	74.1	72.5	72.9	72.5	71.9	71.0
5th—3 internodes									74.6	75.8	75.4	73.6	72.3	72.9	72.2	71.4	70.7
4th—3 internodes							73.0	74.7	74.9	75.7	75.5	73.6	71.1	72.5	71.7	71.6	71.6
3rd—3 internodes						77.3	71.4	73.5	74.5	76.1	75.5	73.7	71.1	72.2	71.2	71.0	69.8
2nd—3 internodes					75.1	75.0	71.0	72.5	74.3	74.9	78.1	72.8	70.2	71.7	70.5	70.3	68.4
1st—3 internodes			80.0	77.2	72.5	74.2	69.1	72.0	74.0	73.5	71.9	71.8	69.6	68.3	66.7	69.2	65.8

plant is common knowledge. More specifically there is a good correlation between the moisture level of the elongating cane and meristem and the daily growth made. In this instance, in order to avoid the factor of temperature, Kailua plants during the summer months were selected and a highly significant correlation of +.756 was obtained between growth and moisture levels of the elongating cane and meristem. Thus, the index tissue must in its moisture variations reflect changes in the levels of the tissues which are active in growth and elongation. Further, it would be highly desirable if the same index were to give an indication of the moisture levels of the cane itself, since moisture levels there are so directly associated with quality.

The tissues which on *a priori* considerations might satisfy the requirements of a general Moisture Index are the blades or sheaths of certain leaves. These organs can be numbered and hence can be collected with a certain precision. Further, the line separating a sheath from a blade, or a sheath from the stem itself is clear, making sharp delimitation possible. For this reason, the use of the elongating cane is difficult since one can never be certain that one internode is still elongating and the adjacent one is mature. This same sort of indefiniteness applies to the meristem. Scattergrams were made using the moisture levels of the elongating cane blades, (leaves 3, 4, 5 and 6 counting the spindle leaf as No. 1), elongating cane sheaths, green-leaf cane blades (all green leaves from No. 7 on) green-leaf cane sheaths, respectively, against the moisture levels of each of the following: the whole plant, the green top alone, all the millable cane including the green-leaf cane, the elongating cane and meristem, the millable cane only for the last 12 months of growth. The scattergrams all indicated approximately linear relationships and hence, correlation coefficients were calculated in order to select the most reliable index. These correlations were made, first, for each plot at each site (Tables III and IV), then the plots at each place were combined into a single population (Tables V and VI), and finally all the plots at both places were combined (Table VII). This procedure in effect determines the applicability of the moisture level in one plot to moisture levels of other adjacent plots planted at different seasons and then to plots growing under two different climatic conditions. For a Moisture Index to be of greatest usefulness, it should indicate similar internal conditions no matter what the external conditions, and at the same time be reliable for small local populations.

An examination of Tables III and IV, representing the correlations taken from the small populations of individual plots, reveals the decided superiority of the elongating cane sheaths over the other three possible indices. One obvious way to rate the four tissues is simply to score them on the basis of the significance of the correlations of these small populations. This is done in Table VIII. It is worthy of note that the tissue most critical to growth, the elongating cane and meristem, for the most part, gives by far the best correlation with the elongating cane sheaths,—correlations of such a nature that they should have predictive value. The same possibilities exist for the "green top" and the "millable cane—last 12 months." These strong correlations are better revealed in Tables V, VI, and VII. By combining all the plots within each climatic area (Tables V and VI) we throw all of the plots, no matter when they were planted, around a common mean. By

TABLE III

CORRELATION COEFFICIENTS*—WAIPIO

(All correlations are positive)

	Elongating cane sheaths	Green-leaf cane sheaths	Elongating cane blades	Green-leaf cane blades
Whole plant:				
Plot A	.717^h	.728^h	.626^h	.586^s
Plot B	.820^h	.843^h	.864^h	.811^h
Plot C	.746^h	.755^h	.783^h	.824^h
Plot D	.621^h	.762^h	.731^h	.803^h
Green top:				
Plot A	.778^h	.805^h	.723^h	.600^s
Plot B	.884^h	.895^h	.892^h	.771^h
Plot C	.685^h	.615^h	.623^h	.650^h
Plot D	.661^h	.652^h	.659^h	.668^h
Millable cane:				
Plot A	.696^h	.692^h	.561^s	.530^s
Plot B	.760^h	.802^h	.817^h	.806^h
Plot C	.723^h	.691^h	.602^s	.648^h
Plot D	.669^h	.551^s	.751^h	.824^h
Millable cane (last 12 months):				
Plot A	.897^h	.614^s	.555^n	.372^n
Plot B	.855^h	.736^h	.720^s	.293^n
Plot C	.782^h	.881^h	.737^h	.539^n
Plot D	.509^n	.089^n	.562^n	.008^n
Elongating cane and meristem:				
Plot A	.703^h	.280^n	.378^n	.064^n
Plot B	.866^h	.776^h	.765^h	.467^n
Plot C	.614^s	.341^n	.158^n	.206^n
Plot D	.853^h	.668^h	.548^s	.423^n

^{h} Indicates correlation is highly significant (beyond 1% level)
^{s} Indicates correlation is significant (between 5 and 1% level).
^{n} Indicates correlation is not significant.
All significant values were obtained using $n-2$.

TABLE IV

CORRELATION COEFFICIENTS*—KAILUA

(All correlations positive except as indicated)

	Elongating cane sheaths	Green-leaf cane sheaths	Elongating cane blades	Green-leaf cane blades
Whole plant:				
Plot A	.732^h	.710^h	.508^s	.614^s
Plot B	.747^h	.819^h	.640^h	.662^h
Plot C	.573^s	.717^h	.534^s	.589^h
Plot D	.516^s	.428^n	.431^n	.350^n
Green top:				
Plot A	.789^h	.537^s	.622^s	.598^s
Plot B	.797^h	.742^h	.602^s	.547^s
Plot C	.666^h	.573^s	.619^h	.432^n
Plot D	.532^s	.443^n	.391^n	.237^n
Millable cane:				
Plot A	.747^h	.737^h	.530^s	.566^s
Plot B	.589^s	.705^h	.337^n	.400^n
Plot C	.287^n	.397^n	—.043^n	.236^n
Plot D	.411^n	.055^n	—.026^n	.285^n
Millable cane (last 12 months):				
Plot A	.640^s	.212^n	.193^n	.129^n
Plot B	.803^h	.338^n	.280^n	.388^n
Plot C	.774^h	.629^s	.407^n	.085^n
Plot D	.823^h	.727^s	.649^s	.449^n
Elongating cane and meristem:				
Plot A	.820^h	.461^n	.712^h	.478^n
Plot B	.790^h	.512^n	.478^n	.032^n
Plot C	.813^h	.550^s	.570^s	.231^n
Plot D	.832^h	.362^n	.334^n	.191^n

* See footnote to Table III.

TABLE V
CORRELATION COEFFICIENTS*—COMBINED

WAIPIO PLOTS

(All correlations positive)

	Elongating cane sheaths	Green-leaf cane sheaths	Elongating cane blades	Green-leaf cane blades
Whole plant	.726^{h}	.765^{h}	.738^{h}	.764^{h}
Green top	.802^{h}	.734^{h}	.730^{h}	.689^{h}
Millable cane	.700^{h}	.681^{h}	.476^{h}	.696^{h}
Millable cane (last 12 months)	.765^{h}	.675^{h}	.639^{h}	.334^{s}
Elongating cane and meristem	.794^{h}	.580^{h}	.512^{h}	.311^{s}

* See footnote to Table III.

TABLE VI
CORRELATION COEFFICIENTS*—COMBINED

KAILUA PLOTS

(All correlations positive)

	Elongating cane sheaths	Green-leaf cane sheaths	Elongating cane blades	Green-leaf cane blades
Whole plant	.608^{h}	.639^{h}	.508^{h}	.540^{h}
Green top	.682^{h}	.533^{h}	.502^{h}	.370^{h}
Millable cane	.472^{h}	.457^{h}	.261^{s}	.251^{n}
Millable cane (last 12 months)	.756^{h}	.464^{h}	.359^{s}	.018^{n}
Elongating cane and meristem	.752^{h}	.445^{h}	.474^{h}	.202^{n}

* See footnote to Table III.

TABLE VII
CORRELATION COEFFICIENTS*—ALL PLOTS

(All correlations positive)

	Elongating cane sheaths	Green-leaf cane sheaths	Elongating cane blades	Green-leaf cane blades
Whole plant	.672^{h}	.720^{h}	.619^{h}	.632^{h}
Green top	.722^{h}	.671^{h}	.624^{h}	.577^{h}
Millable cane	.607^{h}	.589^{h}	.454^{h}	.466^{h}
Millable cane (last 12 months)	.760^{h}	.602^{h}	.497^{h}	.222^{s}
Elongating cane and meristem	.774^{h}	.518^{h}	.457^{h}	.250^{h}

* See footnote to Table III.

TABLE VIII
RELATIVE MERIT OF THE POSSIBLE INDICES

	Elongating cane sheaths	Green-leaf cane sheaths	Elongating cane blades	Green-leaf cane blades
Number of correlations significant beyond 1% level (h)	31	21	15	11
Number of correlations significant between 5% and 1% (s)	6	7	11	7
Number of correlations not significant	3	12	14	22

doing this, however, the populations are increased and hence lower correlations have relatively higher significance. But considering the "green top," the "elongating cane and meristem" and the last 12 months of millable cane, the correlation coefficients with the elongating cane sheaths are of the same high actual values.

Finally, when populations are combined which were planted at different seasons and which were grown under two different climatic conditions (Table VII), the same high correlation coefficients are obtained for the elongating cane sheaths.

Examinations of these tables may cause the reader to wonder why the correlations between the green-leaf cane sheaths and the "whole plant" are not given greater weight in this paper. If the index tissue is to be of value, it should have predictive value for specific tissues, the most important of which is the growing tissue. The growing tissue constitutes a very small portion of the whole plant and if an index correlates well with the whole plant but not so well with particular parts, it is of much less value than an index which correlates very well with important parts and not so well with the whole. Thus, the green-leaf cane sheaths show no significant correlation in five out of eight plots where the growing tissue was involved, yet the "whole plant" correlations are very good except for one case. On the other hand, the elongating cane sheaths show good correlations for *all* of the "whole-plant" populations even though most of the actual correlation values are somewhat less than those obtained for the green-leaf cane sheaths. Further, *all* of the elongating cane and meristem population yield materially superior correlations with the elongating cane sheaths than with the other sheaths. The same general argument may be applied to the "green top" and the "millable cane—last 12 months." These comparisons show up very well in Table VII, where the correlation values are materially higher between the three plant parts and the elongating cane sheaths than they are with any other possible index.

It is because of these comparisons, that the elongating cane sheaths are selected as the Moisture Index of the sugar cane plant. The index tissue is easy to collect, it can be removed from the plant with much precision, and it has shown itself to be reliable for small populations as well as mixtures of populations produced not only in different seasons, but also in different climatic areas. It therefore seems reasonable that a given moisture level in this index tissue reflects certain moisture levels in other parts of the plant, and this is true no matter what the age or location of the crop. One interesting variation has been noted which will appear again later on. It involves the case where a crop has suffered a prolonged drought of several months. Under this stimulus, the plants at a low metabolic level underwent the drought reaction. When in this condition, the elongating cane and meristem contained higher levels of moisture than was indicated by the Moisture Index.

Now that a moisture index tissue has been arrived at, the next phase of this study involves fitting curves to the data obtained and determining whether such curves can be of any predictive value using data from crops not involved in the construction of the curves. In this portion of the study, the level of moisture in the elongating cane sheaths will be used against the moisture levels of the elongating cane and meristem, the green top, and finally the millable cane of the last 12 months.

Elongating Cane and Meristem:

First the simple straight-line equation was calculated from the data. It was found to be $y = 85.56 + .6904\,x$. Thus, where x, the moisture level in the elongating cane sheaths, is 76.5 (coded to 1), y, the level of moisture in the elongating cane and meristem, is 86.25. And where x is 86.5 (coded to 11), y is 93.15. This line is drawn in Fig. 1. From this line, it is now possible to determine the actual goodness of fit. Plotting the actual values obtained, the resulting points are classified according to their actual departure from the line. These results are summarized in Table IX.

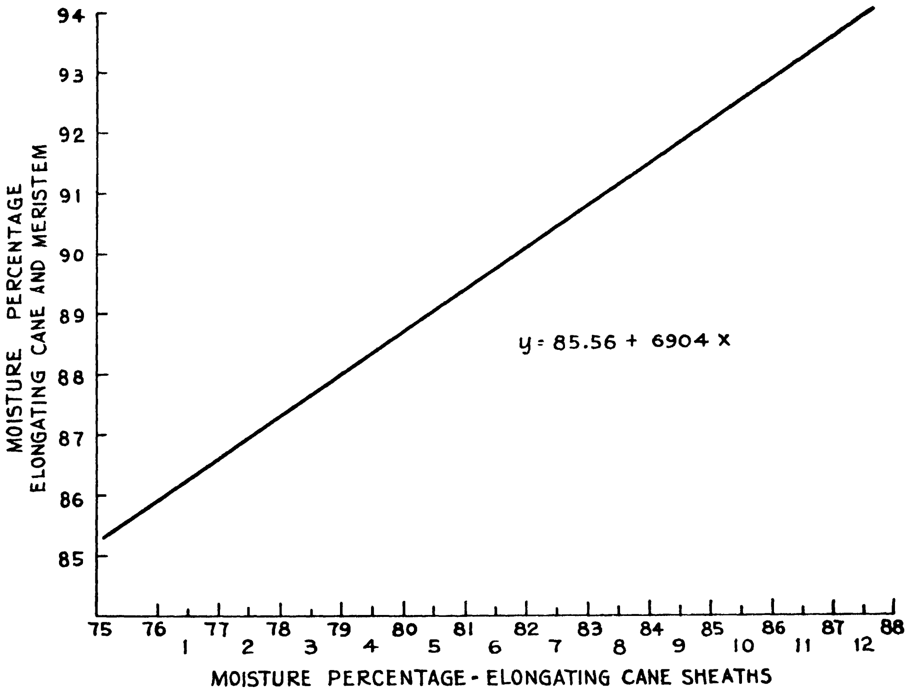

Fig. 1. Relation between moisture content of elongating cane sheaths and elongating cane and meristem.

TABLE IX
GOODNESS OF FIT TO A STRAIGHT LINE*
PLANT CROP

Moisture percentages of the elongating cane and meristem predicted from the moisture percentages of the elongating cane sheaths falling within	Kailua		Waipio		Total	
	No.	%	No.	%	No.	%
0.5 percentage point	17	27.0	23	36.5	40	31.8
1.0 percentage point	38	60.3	40	63.5	78	61.9
1.5 percentage points	53	84.1	54	85.7	107	84.9
2.0 percentage points	59	93.7	59	93.7	117	93.7
>2.0 percentage points of the observed	63	100.0	100	100.0	126	100.0

* $y = 85.56 + .6904\,x$.

TABLE X
GOODNESS OF FIT TO A STRAIGHT LINE*
RATOON CROP

Moisture percentages of the elongating cane and meristem predicted from the moisture percentages of the corresponding elongating cane sheaths falling within	Kailua		Waipio		Total	
	No.	%	No.	%	No.	%
0.5 percentage point	12	26.7	22	48.9	34	37.8
1.0 percentage point	26	57.8	39	86.7	65	72.2
1.5 percentage points	34	75.6	41	91.1	75	83.3
2.0 percentage points	35	77.8	43	95.6	78	86.7
>2.0 percentage points of the observed	45	100.0	45	100.0	90	100.0

* $y = 85.56 + .6904$.

It appears then, that by using a straight line, it is possible to predict about 85 per cent of the moisture levels of growing tissue to within one-and-one-half percentage points of the observed value using the moisture percentages of the corresponding elongating cane sheaths. The next step involves predicting the moisture level of the tissues from the moisture percentages of the elongating cane sheaths not used in calculating the regression line. The data for this trial are taken from the ratoon crops grown after the plant crop. The goodness of fit is reported in Table X.

The predictions for the ratoon crop are particularly excellent for the Waipio crop where more than 90 per cent of the predictions were within 1½ percentage points of the true values. The Kailua ratoons, however, departed somewhat when predictions in ten of the cases were more than 2 percentage points away from the actual. Eight of these ten cases were collections from plants which had been exposed to a prolonged drought. In these, the moisture level of the growing cane was in all cases considerably above what could be predicted from the moisture level of the corresponding sheaths. The point is of interest. Although the plant in building a higher-than-normal moisture level in the growing tissue under drought conditions adds to its survival ability, the growth of the plant does not appear to be affected and remains slow, more in keeping with the level shown by the Moisture Index.

Even though a straight line appears to be a satisfactory fit, the actual distribution of points on the graph suggest that a portion of a parabola might give a better fit. Toward this end, the following equation was determined from the data:

$$y = 84.29 + 1.249 \times -.0443\, x^2.$$

In solving for particular points, the x values in the equation represent the moisture levels of the elongating cane sheaths and are coded as follows: 76.5=1, 77.5=2, etc. up to 87.5=12. The y values are the moisture percentages of the elongating cane and meristem. The resulting curve is shown in Fig. 2.

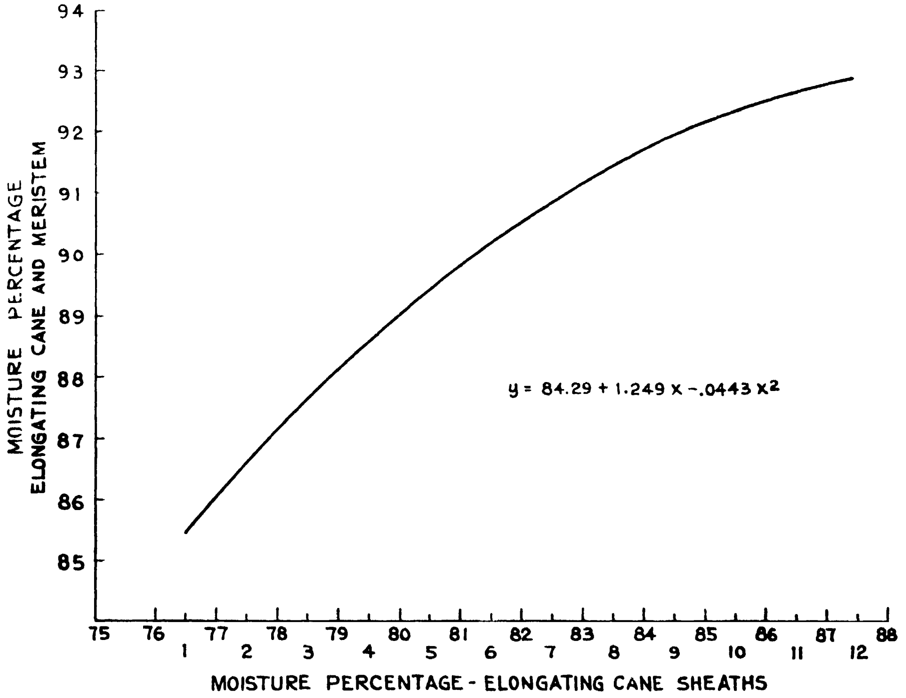

Fig. 2. Relation between moisture content of elongating cane sheaths and elongating cane and meristem.

Again the goodness of fit is recorded for the plant crop in Table XI and for the ratoon crop in Table XII.

TABLE XI
GOODNESS OF FIT TO A CURVE*
PLANT CROP

Moisture percentages of the elongating cane and meristem predicted from the moisture percentages of the corresponding elongating cane sheaths falling within	Kailua		Waipio		Total	
	No.	%	No.	%	No.	%
0.5 percentage point	18	28.6	23	36.5	41	32.5
1.0 percentage point	44	69.8	41	65.1	85	67.4
1.5 percentage points	55	87.3	58	92.1	113	89.7
2.0 percentage points	62	98.4	60	95.2	122	96.8
>2.0 percentage points of the observed	63	100.0	63	100.0	126	100.0

* $y = 84.29 + 1.249 \times -.0443\, x^2$.

TABLE XII
GOODNESS OF FIT TO A CURVE*
RATOON CROP

Moisture percentages of the elongating cane and meristem predicted from the moisture percentages of the corresponding elongating cane sheaths falling within	Kailua		Waipio		Total	
	No.	%	No.	%	No.	%
0.5 percentage point	18	40.0	18	40.0	36	40.0
1.0 percentage point	33	73.3	40	88.9	73	81.1
1.5 percentage points	35	77.8	43	95.6	78	86.7
2.0 percentage points	36	80.0	43	95.6	79	87.8
>2.0 percentage points of the observed	45	100.0	45	100.0	90	100.0

* $y = 84.29 + 1.249 \times -.0443\, x^2$.

When the last column of Table XI is compared with that of Table IX, there appears to be a slight improvement in the fitting. From Table XII, it may be observed that the ratoon crop can be predicted with considerable accuracy. Whether it will be better to use a straight line or a curve can best be determined at a later date when a much larger number of observations have been made. To be sure, from the point of view of the fieldman, it will not be necessary to use such a curve at all, since if it is known that a relationship exists between the moisture level of the sheaths and that of the growing tissue, one need only concern himself with maintaining the level in the sheaths in one range during growth activity and in another during maturation of the crop. At the present stage, it appears that for variety 31–1389, the range in moisture level of the sheaths associated with rapid growth is between 83.5 and 85.5. Values above 85.5 appear to indicate overwatering. Growth curtailing begins when the index drops to about 82.5 per cent and becomes more severe as the index drops. The lowest value for the Moisture Index so far observed in field-grown plants was 76.2 per cent; the highest, 88.6 per cent.

Green Top:

To predict the moisture level of the whole green top from the level of moisture of the elongating cane sheaths requires a new equation. By calculation, it is found to be

$$y = 74.5844 + .7606\, x$$

where $x=1$ (76.5%) $y=75.35$ and where $x=11$ (86.5%) $y=82.95$. In Table

XIII, the goodness of fit is reported for the plant crop from which the equation was calculated and in Table XIV, a similar tabulation is recorded for the ratoon crop which did not enter into the calculation of the equation.

TABLE XIII
GOODNESS OF FIT TO A STRAIGHT LINE*
PLANT CROP

Moisture percentages of the green top predicted from the moisture percentages of the corresponding elongating cane sheaths falling within	Kailua		Waipio		Total	
	No.	%	No.	%	No.	%
0.5 percentage point	18	25.3	20	28.2	38	26.7
1.0 percentage point	44	62.0	33	46.5	77	54.3
1.5 percentage points	59	83.1	40	56.9	99	70.0
2.0 percentage points	60	84.4	51	71.8	111	78.1
>2.0 percentage points of the observed	71	100.0	71	100.0	142	100.0

* $y = 74.5844 + .7606x$.

TABLE XIV
GOODNESS OF FIT TO A STRAIGHT LINE*
RATOON CROP

Moisture percentages of the green top predicted from the moisture percentages of the corresponding elongating cane sheaths falling within	Kailua		Waipio		Total	
	No.	%	No.	%	No.	%
0.5 percentage point	18	40.0	14	31.1	32	35.6
1.0 percentage point	24	58.3	25	55.6	49	54.4
1.5 percentage points	35	77.8	31	68.9	66	73.3
2.0 percentage points	37	82.2	34	75.6	71	78.9
>2.0 percentage points of the observed	45	100.0	45	100.0	90	100.0

* $y = 74.5844 + .7606x$.

It is clear that even so diverse a collection of tissues as is found in the green top can be successfully correlated with the index chosen. The predictions for the ratoon are fully as good as for the plant crop. However, the fit is not so good as was observed for the elongating cane and meristem. The greater departure in this case is to be expected, however, since there is such a large diversity of tissues involved. However, when it is possible to estimate the moisture percentage of over 70 per cent of the population to within one-and-one-half percentage points, it clearly indicates considerable precision.

Attempts to fit other equations to the population resulted in a straight line each time.

Millable Cane—Last 12 Months:

The fieldman is seriously concerned with the moisture content of the millable cane since good quality ratios are associated with low moisture content. At first it was hoped that the millable cane including the green-leaf cane could be correlated successfully with the sheaths from the very beginning of the crop, but Tables III and IV indicate no high degree of reliability. The reason for this is quite clear when it is remembered that in the young stage, the succulent green-leaf cane makes up a very large part of the whole cane. However, since the fieldman's real concern centers around the crop as it approaches harvest, an effort was made to determine the correlations for the last 12 months of the cane. That is, for a 22-month crop, the correlations were begun when the crop was 10 months old. Now, if one is growing a short-cycle crop, he should still begin not earlier than 10 months. But even so he would still have from 2 to 6 months in which to control the moisture levels.

Reference to Tables III-VII indicates a good correlation between the moisture level of the "millable cane—last 12 months" and the moisture level of the Moisture Index, the elongating cane sheaths. The straight-line equation for this relationship is

$$y = 69.81 + .753\,x$$

where $x=1$ (76.5), $y=70.56$ and where $x=11$ (86.5), $y=78.84$. Plotting the data obtained for the plant crop results in a fair degree of precision (Table XV). The fit for the ratoon crop is poor (Table XVI). The next attempt was to fit a curve to the data. The equation obtained is

$$y = 71.8 - .1658x + .0766\,x^2.$$

TABLE XV

GOODNESS OF FIT TO A STRAIGHT LINE*

PLANT CROP

Moisture percentages of the millable cane—last 12 months predicted from the moisture percentages of the corresponding elongating cane sheaths falling within	Kailua		Waipio		Total	
	No.	%	No.	%	No.	%
0.5 percentage point	11	25.0	7	15.9	18	20.5
1.0 percentage point	21	47.7	12	27.3	23	37.5
1.5 percentage points	26	59.1	23	52.3	49	55.7
2.0 percentage points	37	84.1	33	75.0	70	79.6
>2.0 percentage points of the observed	44	100.0	44	100.0	88	100.0

* $y = 69.81 + .753\,x$.

TABLE XVI

GOODNESS OF FIT TO A STRAIGHT LINE*

RATOON CROP

Moisture percentages of the millable cane—last 12 months predicted from the moisture percentages of the corresponding elongating cane sheaths falling within	Kailua		Waipio		Total	
	No.	%	No.	%	No.	%
0.5 percentage point	1	5.8	4	23.5	5	14.7
1.0 percentage point	3	17.6	7	41.2	10	29.4
1.5 percentage points	6	35.3	8	47.1	14	41.2
2.0 percentage points	13	76.5	10	58.8	23	67.7
>2.0 percentage points of the observed	17	100.0	17	100.0	34	100.0

* $y = 69.81 + .753\,x$.

Plotting the data against this curve (Fig. 3) results in a material improvement in the goodness of fit, both for the plant crop (Table XVII) and the ratoon crop (Table XVIII). Thus, in the plant crop, 27.3 per cent of the cases were within 0.5 percentage point of the observed, 60.2 per cent of the cases were within 1.0 per cent and 79.5 per cent were within 1.5 percentage points of the observed. Although the ratoon crop at Kailua fits well, that grown at Waipio departed from predictions even though more than half of the cases fell within 1.5 percentage points of the observed. Perhaps as time goes on and more data are available it will be possible to draw curves for each island area, and in this way achieve a higher order of precision.

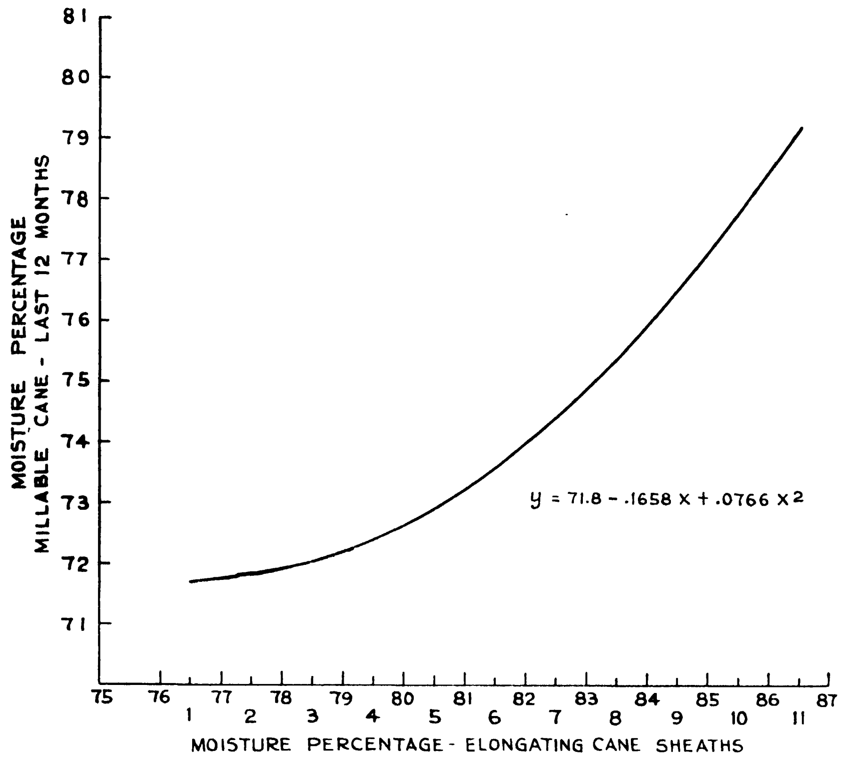

Fig. 3. Relation between moisture content of elongating cane sheaths and "millable cane—last 12 months."

CONCLUSION

As a result of these correlations, it is safe to conclude that the moisture level of the elongating cane sheaths is a true index to the moisture levels of the growing tissues of the cane plant as well as of the mature millable cane. Since it has been shown that the Moisture Index is reliable not only for small local plots but also for plots started at different times of the year, and in different climatic areas, it is safe to presume that the level of moisture observed is the result of the integration by the plant of all factors, external and internal, affecting its moisture relations. Consequently, it is reasonable to suppose that the irrigation program will best fit a particular crop if it is based upon a running picture of the conditions within the plant as portrayed by the Moisture Index.

TABLE XVII

GOODNESS OF FIT TO A CURVE*

PLANT CROP

Moisture percentages of the millable cane—last 12 months predicted from the moisture percentages of the corresponding elongating cane sheaths falling within	Kailua		Waipio		Total	
	No.	%	No.	%	No.	%
0.5 percentage point of the observed....	13	29.5	11	25.0	24	27.3
1.0 percentage point of the observed....	31	70.5	22	50.0	53	60.2
1.5 percentage points of the observed...	36	81.8	34	77.3	70	79.5
2.0 percentage points of the observed...	37	84.1	39	88.6	76	86.3
2.0 percentage points of the observed...	44	100.0	44	100.0	88	100.0

* $y = 71.8 - .1658\,x + .0766\,x^2$.

TABLE XVIII
GOODNESS OF FIT TO A CURVE*
RATOON CROP

Moisture percentages of the millable cane—last 12 months predicted from the moisture percentages of the corresponding elongating cane sheaths falling within	Kailua		Waipio		Total	
	No.	%	No.	%	No.	%
0.5 percentage point of the observed....	4	23.5	3	17.6	7	20.6
1.0 percentage point of the observed....	8	47.1	7	41.2	15	44.1
1.5 percentage points of the observed...	13	76.5	9	52.9	22	64.7
2.0 percentage points of the observed...	13	76.5	11	64.7	24	70.6
2.0 percentage points of the observed...	17	100.0	17	100.0	34	100.0

* $y = 71.8 - .1658\,x + .0766\,x^2$.

SUMMARY

1. The moisture relations of eight plantings of sugar cane are analyzed and discussed.
2. The elongating cane sheaths are shown to be the most reliable tissue to be used as a Moisture Index.
3. Satisfactory correlations are found between the levels of the Moisture Index and the green top of the plant, the elongating cane and meristem, and the mature cane, respectively.
4. Curves and/or straight lines are fitted to the data and from these, the moisture levels of tissues of the ratoon crops are predicted. The predicted values fall sufficiently close to observed values to be used in determining a practical irrigation program.

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Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
SEPTEMBER 22, 1941, TO DECEMBER 1, 1941

Date	Per pound	Per ton	Remarks
Sept. 22, 1941	3.53¢	$70.60	Philippines.
Oct. 17	3.51	70.20	Cubas.
" 21	3.53	70.60	Philippines.
" 24	3.57	71.40	Philippines.
Dec. 1	3.51	70.20	

THE HAWAIIAN PLANTERS' RECORD

Vol. XLVI SECOND QUARTER 1942 No. 2

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

In this issue:

Juice Quality Affected by Lodging:

Lodging of sugar cane, generally caused by heavy winds or rains, results in a poorer quality and an actual loss of sugar especially in that part of the stalk which remains recumbent. These effects are apparently not modified by supplying extra nitrogen fertilizer to cane which has already received nitrogen at a high level.

New Caledonian Cockroach Parasite:

Illustrating the habits of a brilliant blue-green wasp that destroys our large household cockroaches. This wasp was imported from New Caledonia and reared in the laboratory.

Notes on the Temporary Establishment of Insect and Plant Species on Canton Island:

The recent establishment on Canton Island of certain insects is described. Reasons are given for believing that these insects, as well as plants sprouting from ocean-borne seeds as a result of recent ample rainfall, will eventually die out due to the almost certain recurrence of semi-arid conditions.

Filter-Cake Compost:

The decomposition of fresh filter cake under laboratory and field conditions and the nutritive value of the final product—filter-cake compost—are discussed. The results of the investigations showed that decomposition was completed within from 5 to 7 months, and that the fresh filter cake was adequately supplied with the necessary nutrients for the development of the organisms which were responsible for its decomposition.

Are There Possibilities in Subsoil Fertilization?

Soils removed from the surface foot and from the subsoil of cultivated cane fields, although differing widely in their available nutrient content, have been made to produce comparable yields when adequately fertilized. This fact suggests that subsoil fertilization, to more nearly equalize the availability of nutrients in surface soils and subsoils, ought to result in a more extensive and efficient root system for sugar cane.

Boron in Some Hawaiian Soils and Crops:

The boron content of Hawaiian soils, soil-forming materials, irrigation waters, and economic crops has been determined. Consideration is also given to boron fixation and the availability of water-soluble soil boron. The total soil boron is highest in surface soils and ranges from 4 to 56 p.p.m. Old uneroded soils from high rainfall regions contain the most total boron. Water-soluble boron is also highest in surface soils and ranges from 0.4 to 3.2 p.p.m. A significant relationship is found between soil pH and water-soluble boron. Hawaiian soils fix boron from dilute solutions of boric acid. The distribution of boron in various organs of sugar cane, pineapple plants and other crops grown in both high and low boron mediums is discussed. A normal crop of sugar cane removes less than 0.5 pound of boron per acre.

Rainfall Evaluation as an Aid to Irrigation Interval Control:

A method of rainfall evaluation, based on hundreds of concurrent soil-moisture observations and temperature records, has been devised and is fully described. This evaluation of rainfall in terms of day-degrees has been of great assistance in controlling irrigation intervals at Waipio Substation inasmuch as the control is relatively simple to operate, and since seasonal variations are automatically taken into account by the use of day-degrees to measure intervals.

The table of rainfall evaluation for adjusting irrigation intervals at Waipio is described, and the procedure for its use explained and demonstrated. Tables for rainfall evaluation on eight other standard types of soils are available. When selected judiciously for specific local soil types, these tables should operate with as satisfactory results as have been obtained at Waipio.

Juice Quality Affected by Lodging

By R. J. Borden

Statements to the effect that the quality of the juice of canes which have lodged is poorer than that of erect canes are not uncommon, but it is somewhat difficult to find actual data to support such assertions. However, the tendency of some otherwise good cane varieties to lodge causes discrimination against such canes in several sugar-producing countries and, therefore, the issue becomes one in which we in Hawaii should be interested, since we have a tendency to accept this growth habit without serious question, justifying our complacence with the realization that lodging generally signifies a heavy cane tonnage, and that there is little we can do about it anyway. But, this attitude should not prevent our search for the facts, and we conducted a well-controlled skirmish test* to find out what actually happens to cane which "goes down."

Plan: The plan which we used to study this objective was as follows: 36 Mitscherlich pots containing Manoa soil were each planted with two single-eye cuttings of 31–1389 cane on January 29, 1941 and grown under uniform conditions until September 1. To find out whether an extra application of nitrogen, made sufficiently in advance of the time the cane "goes down" to be quite completely taken up, would alter the effects of lodging, half of the pots (Series A) were given an extra application of ammonium nitrate. One month later, 9 pots from this Series A and a corresponding 9 pots from a control Series B (which did not get the extra nitrogen) were laid on their sides so that the stalks were left in a horizontal or lodged position (Position No. 2); the remaining 9 pots were left in their original erect positions (Position No. 1). From this time until the canes were harvested on Feb. 3, 1942, similar treatment was given to all pots.

At the time of assigning the individual pots to their respective positions, each primary stalk was permanently marked at its uppermost dry-leaf internode; this mark provided a means for dividing these stalks at harvest into (1) a lower section, which was already mature stalk before the positional differential was imposed, and (2) an upper section which matured thereafter.

Observations: Within 3 days after imposing the horizontal position, the stalks had turned up their tops at approximately a 45° angle to their basal portions, and at 6 days this angle was at 90° and the top portions of the stalks were again erect and remained so until harvested. It should be recorded that these 6 days came during a period of bright sunny weather.

The accompanying photograph (Fig. 1) shows the position of the lodged canes as they were at harvest; also the position of the "controls" which were erect throughout the whole growing period.

Results: At harvest the primary stalks from each replicate were separated into their lower and upper portions, and these sections were then measured, weighed, and crushed for juice analyses. In addition the millable cane portions of all suckers were composited, according to treatments, since there was an inadequate amount of millable cane from the sucker growth to provide for individual analyses of juices.

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* **Project A–105 No. 166.**

The harvest results are summarized in Table I and the data have been studied for their significance by an analysis of variance of the 2 x 2 factorial plan which was used. Since there was no evidence of any interaction between the two nitrogen levels and the two positions, the averages (except for the sucker growth) as listed in Table I are from the 18 replicates of each of the main factors.

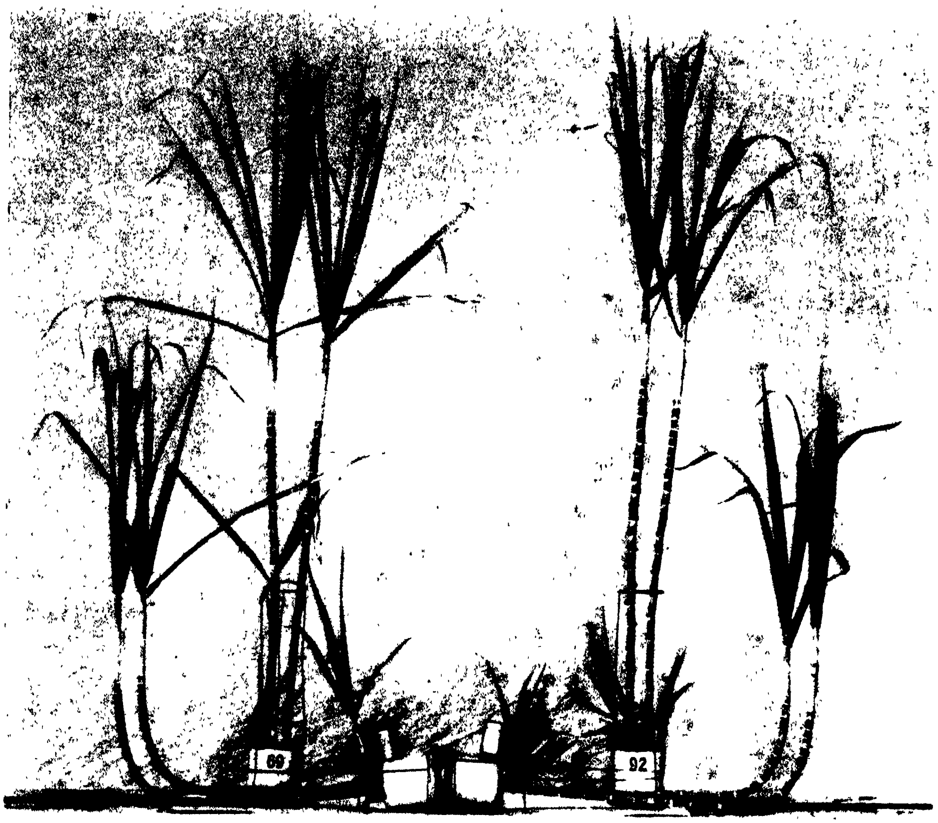

Fig. 1. Positions of lodged canes and their "controls." The pair on the right received extra nitrogen.

TABLE I

(a) EFFECTS ON *LOWER* PORTIONS OF STALKS

	Stalk position		Nitrogen applied	
Measurement	No. 1—erect	No. 2—lodged	A=extra N	B=control
Purity	94.3 *	91.5	92.4	93.3
Pounds cane	1.93*	1.61	1.82	1.73
Y%C	15.6 *	13.7	14.5	14.8
Pounds sugar	.30*	.22	.27	.26
Length (ft.)	2.46*	2.06	2.29	2.23

(b) EFFECTS ON *UPPER* PORTIONS OF STALKS

Measurement	Stalk position		Nitrogen applied	
	No. 1—erect	No. 2—lodged	A=extra N	B=control
Purity	93.8 *	90.7	91.4	93.2*
Pounds cane	2.00	2.20	2.09	2.12
Y%C	15.1 *	13.5	14.0	14.6
Pounds sugar	.30	.30	.29	.31
Length (ft.)	2.51	2.68	2.57	2.62

(c) EFFECTS ON SUCKERS

Measurement	Stalk position		Nitrogen applied	
	No. 1—erect	No. 2—lodged	A=extra N	B=control
Purity	90.1	87.9	88.5	89.6
Total lbs. cane	3.31	2.47	3.20	2.58
Y%C	13.7	12.3	12.8	13.1
Total lbs. sugar	.45	.30	.41	.34

* Only these figures are proved significantly greater than the corresponding figure for the respective differential. No statistical analyses were made on the data from suckers as these replicates were not kept separate.

Discussion: The only significant effect that was measured on these canes, from the difference in the nitrogen applied, was that a slightly poorer purity was found in the crusher from the upper portions of those stalks which had received the extra nitrogen; this is an effect which has been measured many times previously in other investigations. Furthermore there was no indication of any modification of the measured effects of lodging by the different amounts of nitrogen that were applied. Hence no further discussion of the nitrogen factor in this present study need be indulged in.

The effects on sugar cane stalks which lodge or "go down" are quite clearly seen to be chiefly effects on the cane quality, and we note that the crusher juice purity and the yield-per-cent-cane (Y%C) of both the lower portions of the stalks which were mature before lodging took place, and of the upper portions which matured thereafter, were quite similarly affected. It might also appear that the juices of millable cane from the suckers which grew after the cane had lodged had also been adversely influenced, although it is a bit difficult to conceive why this should be so.

Although it had been assumed that a comparable distribution of the 36 pots had originally been made between the two positional differentials, and that each stalk had been fairly marked at its uppermost dry-leaf internode, the measurements and cane weights taken at harvest, which show significantly more cane on the lower portions of the stalks which had remained erect, may indicate that our original distribution of replicates was faulty, for we have no well-established grounds for believing that the length of this mature stalk portion would actually shrink, although we might concede a loss in weight if it is assumed that some sugars were used up in bringing the tops from their horizontal to an erect position again. However, we make these measurements, as secured, a matter of record.

The loss in sugar which has occurred in the lodged cane is significant only for the lower section of the stalk which was already mature when lodging occurred; this sugar loss appears to be in the neighborhood of 25 per cent. No similar effect was found on the recoverable sugar from the upper parts of the stalks which matured after lodging occurred. Perhaps a fairer estimate of the total loss of sugar from the lodged canes is contained in a comparison of the total amounts of the cane and sugar recovered from the 18 pots which carried the lodged canes and the other 18 with their erect stalks; the difference is still a considerable amount and is seen to be primarily due to the poorer juice quality from the cane that "went down," e.g.

Position	Total lbs. cane	Total lbs. sugar	Avg. Y%C
1—Erect	74.23	11.43	15.4
2—Lodged	71.23	9.66	13.6
Difference	3.00	1.77	1.8
% lost	5.0	15.5	11.7

Conclusion: A definitely poorer juice quality has been measured as an effect of lodging, and this in turn has resulted in an actual loss in recoverable sugar. Apparently these effects from lodging were not altered by increased nitrogen fertilization.

The New Caledonian Cockroach Wasp *(Ampulex Compressa)* in Hawaii

By Francis X. Williams

Illustrated by W. Twigg-Smith

In May 1940 the Experiment Station of the Hawaiian Sugar Planters' Association sent the writer to New Caledonia to study the insects of economic importance of that large island. Inasmuch as Noumea, capital of New Caledonia, is a stopping point for the Pan American Airways' Clipper ships plying between the California coast and New Zealand and, touching of course at Honolulu, it is important to know what pests, particularly those attacking sugar cane, are found in New Caledonia so as to better guard against their accidental importation here.

A large collection of economic insects was made during the four-month stay in New Caledonia. This collection is being studied and will be reported on at a later date. Living specimens of a large wasp that preys on cockroaches were introducted into Honolulu, and are apparently established here. This insect, technically known as *Ampulex compressa*, forms the subject of the present paper.

The habits of this wasp, a brilliant, chiefly blue-green jewel of an insect nearly an inch long, have been known to science in some detail for 200 years. It inhabits parts of Asia, Africa, island of St. Helena, islands of the Indian Ocean as well

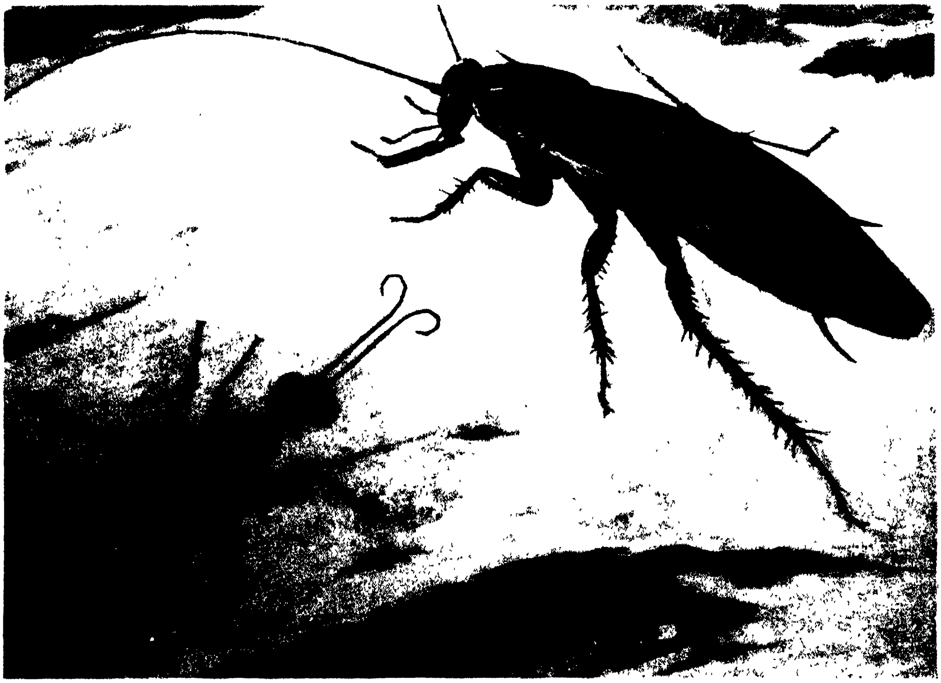

Fig. 1. The wasp finds the cockroach.

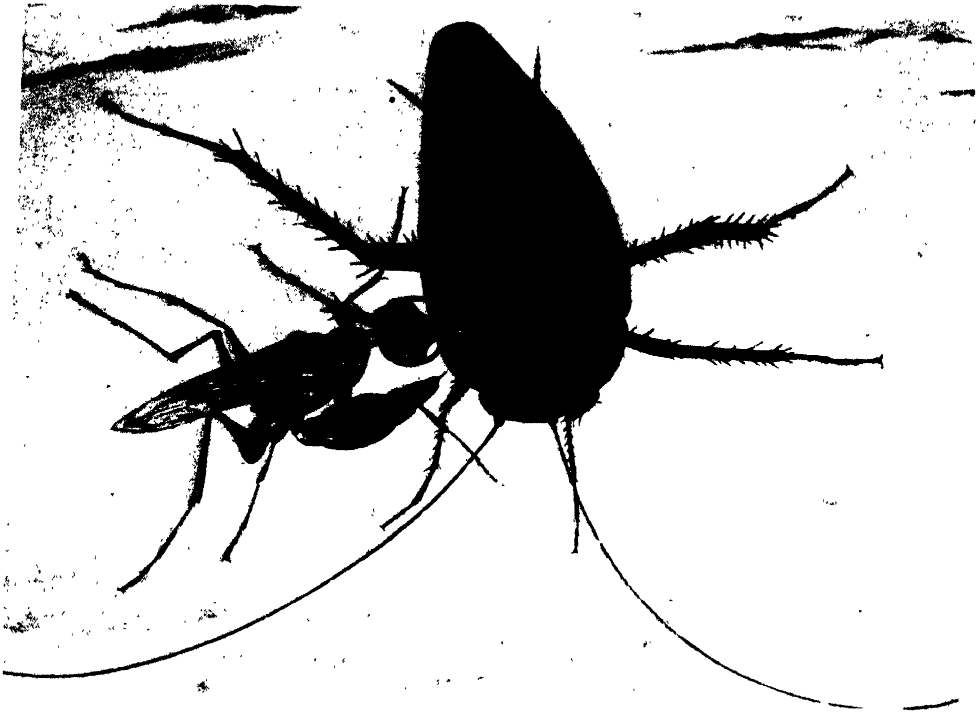

Fig. 2. She attacks—stinging the cockroach in breast and throat.

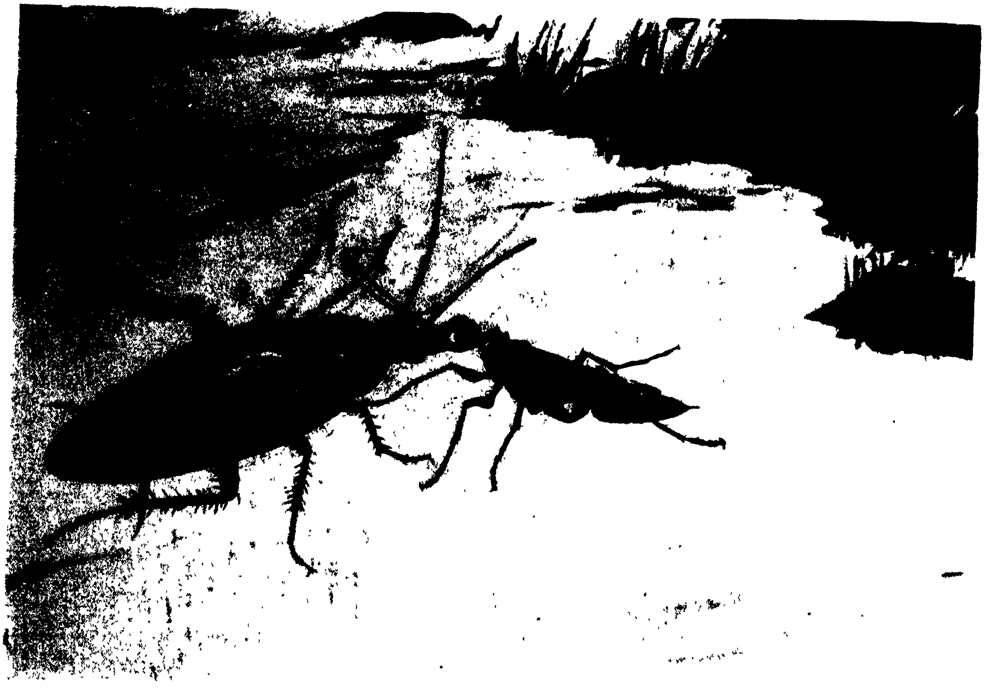

Fig. 3. The disabled cockroach is dragged into a hole.

as the island of New Caledonia. It is an inveterate enemy of our common large cockroaches. In Noumea it is called the "cantharide," and in the summer time—our winter season—is abundant there; but it was still quite rare in early November when Mrs. Williams and I were preparing to return to Honolulu. Of the six female *Ampulex* seen in Noumea, four were captured. Of these, one was injured in its capture and a second died within three weeks. The other two were taken with us to Honolulu via Pan American Airways and lived 74 and 102 days respectively. Also brought back from Noumea were a number of large cockroaches parasitized by the three wasps, of which the two long-lived ones parasitized several dozen additional cockroaches during their captivity in Honolulu. This living *Ampulex* material has been sufficient for its establishment on the island of Oahu. Wasps at large have now been seen in Honolulu for well over a year after their liberation.

The several illustrations accompanying this paper clearly indicate the chief activities of *Ampulex compressa.*

Fig. 1 shows an *Ampulex* that has just discovered a large cockroach. The wasp measures four-fifths of an inch and the cockroach is twice as long and several times her bulk. The very alert wasp, her antennae held close together forward, is manouvering to one side of the still unsuspecting cockroach in preparation for a lightning attack upon it.

In Fig. 2 the wasp has leaped forward to grip the thoracic plate of her prey, edge on, between her clypeus and labrum above and her curved mandibles beneath. Almost at the same instant she directs her extensile abdomen forward beneath her chest to sting the cockroach in its soft underpart between the legs and in the throat, with a semi-paralyzing effect.

In Fig. 3, following the regular procedure, *Ampulex* has cut off a considerable length of the cockroach's antennae and is dragging it by the base of one antenna to a hole she has discovered. She drags her more or less resisting prey into this retreat and glues an egg to the base of one leg of its middle pair. Now she imprisons her prey by plugging up the hole with debris.

In Fig. 4 we have taken out this parasitized cockroach and placed it on its back to show the wasp's egg in place (left) and, a few days later, the same cockroach showing the wasp grub that has developed from the egg (right). Note that the parasite is in such a position on the cockroach that it can not usually be rubbed off or injured by any movement. The wasp grub thus feeds externally on its host for three or four days. Somehow it has secured nourishment with the help of its delicately spine-tipped jaws. It sheds its skin for the fourth time to acquire a strong stout-toothed pair of jaws with which it immediately bites its way into the cockroach's body and devours the interior. The cockroach soon perishes.

Fig. 5 (left) illustrates a cockroach cut open to expose the feeding *Ampulex* wasp grub within its abdomen. The dead and internally devoured cockroach soon stiffens into a mere shell. Herein the full-grown wasp grub spins a silky brown cocoon (Fig. 5, right) enveloping a hard dark cask within which, sooner or later, depending on the season, it changes into a pupa.

In due time the pupa within the cocoon produces the brilliant blue-green wasp that bites its way out to freedom (Fig. 6).

The wasp's life, as egg, larva and pupa, on and within the cockroach, varies

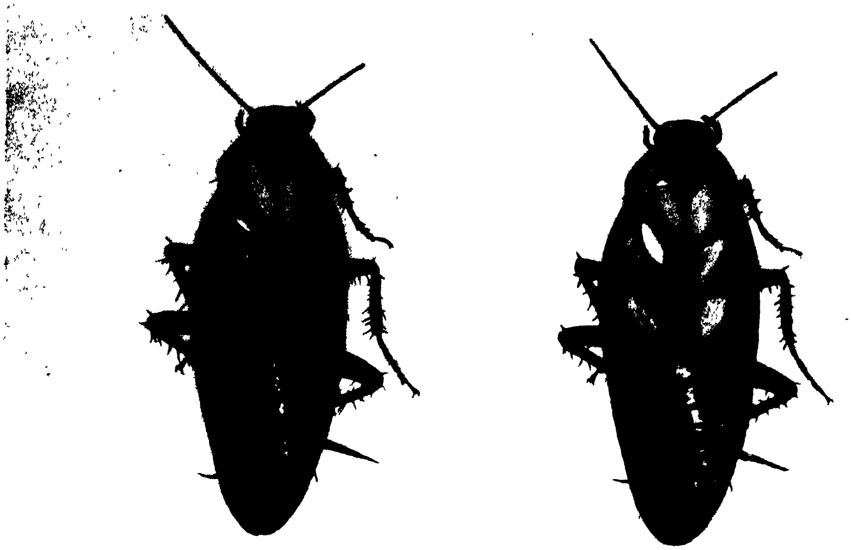

Fig. 4. The wasp lays an egg on the cockroach, the egg hatches into a grub, and the grub eats its way into the cockroach.

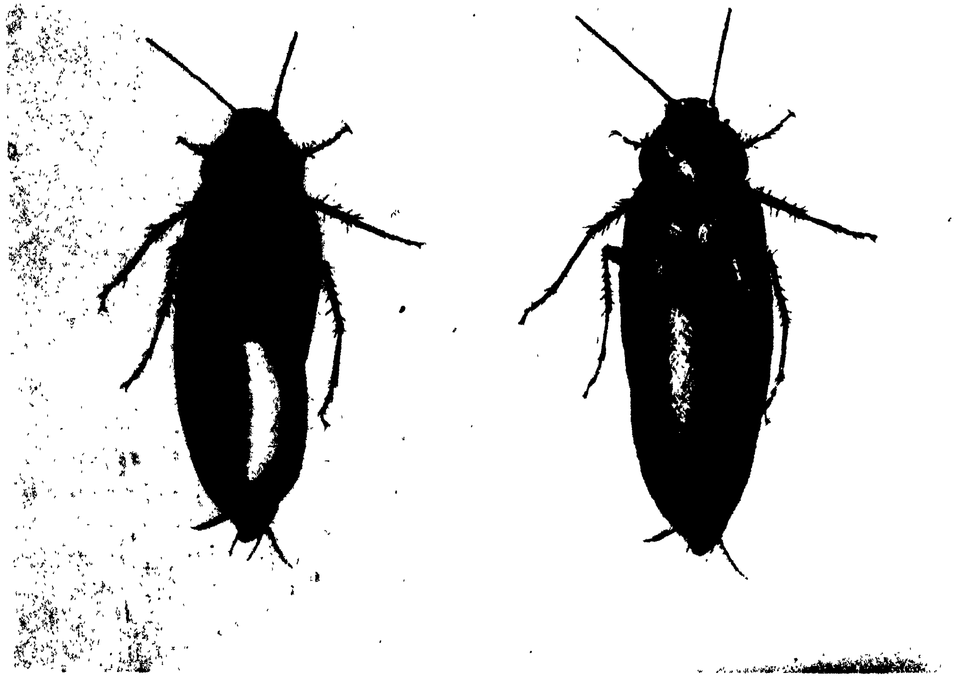

Fig. 5. The cockroach lives only a few days longer while the grub feeds upon it. When the grub is full-grown, it spins a cocoon inside the cockroach.

from a little more than one month to four months or more.

Three kinds of cockroaches are successfully used by *Ampulex.* These are: *Periplaneta americana,* the large brown roach; *Periplaneta australasiae,* a smaller but still quite large roach; and *Neostylopyga rhombifolia,* a somewhat rare wingless species of large size and conspicuous color pattern.

This beautiful blue-green wasp readily attacks her prey within the confines of a large jar, and she as readily accepts the carton tube, plugged at one end, as a nest hole in which to store her cockroach prey. Her several activities—the fierce attack, the dragging-in of the subdued roach, and the stuffing of the stored tube with the debris at hand—have been witnessed here by many people and with great interest.

Ampulex compressa lives a long time. The longest record for the male is 85 days. Several others survived for over two months.

The following table shows the longevity of sixteen females and the number of cockroaches stored by some of these wasps:

Captured in New Caledonia	Died	Days longevity	No. cockroaches stored
October 15, 1940	Nov. 4, 1940	20	Not recorded
‘‘ 17, 1940	Dec. 30, 1940	74	About 65
‘‘ 31, 1940	Feb. 10, 1941	102	About 78
Hatched in Honolulu			
January 6, 1941	May 11, 1941	125	85
‘‘ 23, 1941	‘‘ 12, 1941	109	88
May 12, 1941	June 12, 1941	31	20
‘‘ 15, 1941	‘‘ 20, 1941	36	25
‘‘ 15, 1941	Sept. 11, 1941	119	65
‘‘ 25, 1941	‘‘ 9, 1941	107	55*
June 9, 1941	Oct. 10, 1941	123	49*
‘‘ 20, 1941	‘‘ 9, 1941	111	41*
Sept. 15, 1941	Dec. 16, 1941	92	33*
October 16, 1941	Feb. 12, 1942	129	46*
‘‘ 6, 1941	‘‘ 17, 1942	134	43*
‘‘ 13, 1941	March 12, 1942	150	39*
‘‘ 24, 1941	April 1, 1942	159	57*

* Indicates that these individuals were supplied with cockroaches at longer intervals, of from two to several days. Aged wasps were usually too stiff, short-winded and of insufficient vigor to successfully cope with a large cockroach. Thus such wasps, and rather undersized ones too, were often supplied with small (younger) cockroaches so as not to overtax their strength.

The wasp has been liberated chiefly in Honolulu where it has been seen at large over a period of many months. It is being shipped to the other islands of the Hawaiian group. To date over 200 females have been set free.

How this wasp will affect the population of large cockroaches remains to be seen. Many cockroaches will be destroyed by it, but it is doubtful if these hardy and adaptable pests will thereby be greatly reduced. However, every cockroach enemy helps.

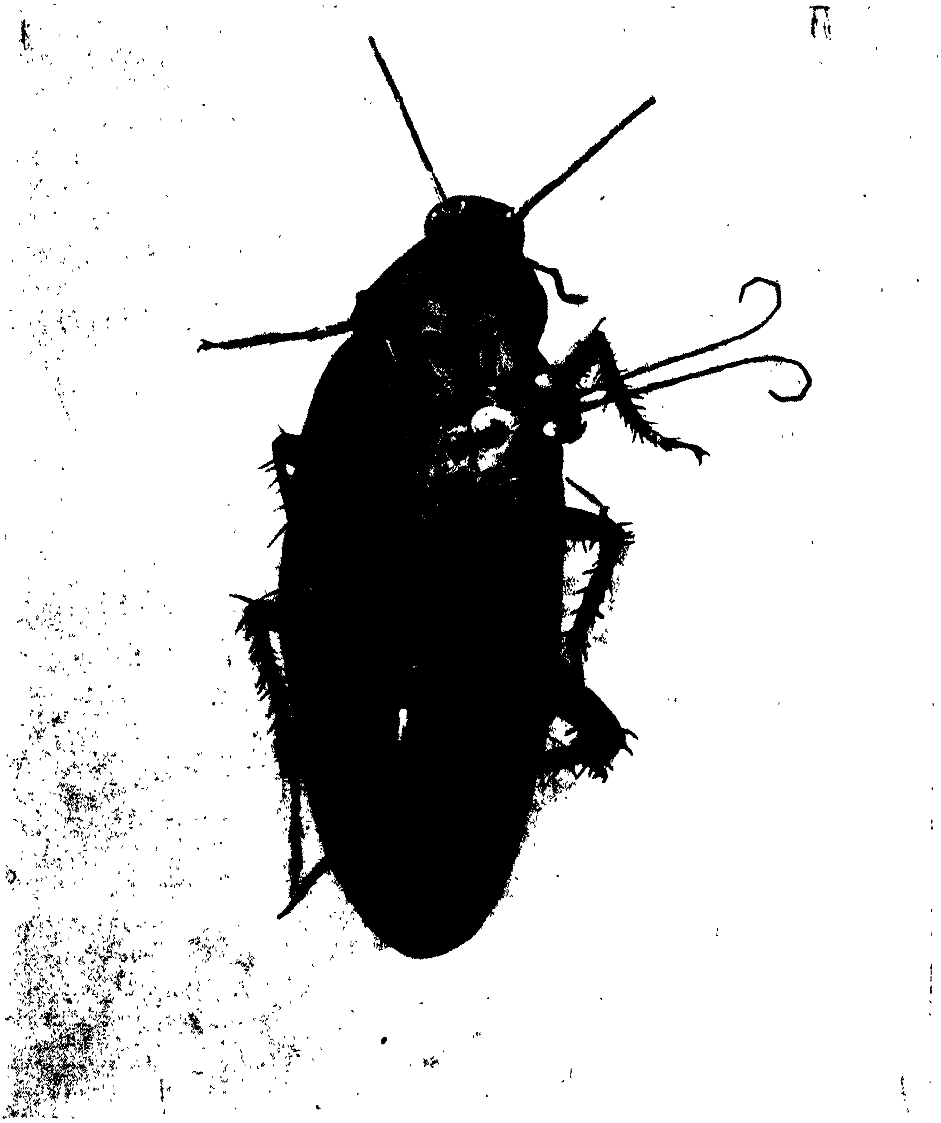

Fig. 6. A few weeks later a new-born wasp comes out.

Notes on the Temporary Establishment of Insect and Plant Species on Canton Island

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By R. H. VAN ZWALUWENBURG

Canton Island, a typical coral atoll in mid-Pacific at 2° 49′ south latitude and 171° 40′ west longitude and the first station southward on the Pan American Airways route from Hawaii to New Zealand, presents interesting problems involving the temporary establishment of certain insect and plant species. The insect and plant problems involve the variance in annual rainfall; those concerning the establishment of plant species involve, besides, the ocean currents which transport floating seeds to the island. These notes are based on observations made on Canton during some 16 weeks spent there in the late summers of 1940 and 1941.

Numerous small low islands in the central Pacific are relatively near, but Canton is well removed from high island archipelagoes and major land masses. Approximate distances in nautical miles, stated in round numbers, are as follows:

From Canton to	Samoa	700	miles
	Fiji	1000	"
	Tahiti	1550	"
	Hawaii	1600	"
	Solomons	1700	"
	New Britain	2150	"
	New Guinea	2300	"
	Galapagos	4900	"
	Ecuador	5500	"

Although properly considered to be a dry island,* Canton has a rainfall which varies greatly from year to year and which at times is relatively heavy, providing, at least temporarily, conditions favorable for the establishment of certain plants and insects. Weather data for Canton are available only since the latter part of 1937. The rainfall totalled 8.7 inches in 1938; it has since increased year by year until in 1941, 83.7 inches had fallen by the end of August. Similarly wide variations are recorded from nearby islands (Bryan, l.c., p. 16): Malden (a dry island) from 3.9 to 93.5 inches; and Fanning (a wet island) from 47.4 to 208.8 inches. It seems inevitable that eventually Canton will again experience periods of very low rainfall.

Two years of good rains have resulted in a thriving growth of native vegetation on Canton at the present time. On areas described as "desert" in the spring of 1939, there is a heavy cover of *Sida fallax* Walpers (shoulder high in many places) associated with *Boerhaavia diffusa* L., *Triumfetta procumbens* Forster, *Portulaca lutea* Solander and three species of bunchgrass (Digitaria, Eragrostis and Lepturus). (See Fig. 1.)

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* Bryan, Edwin H., Jr., 1941. American Polynesia—Coral Islands of the Central Pacific. Tongg Publishing Company, Honolulu, 208 pp., numerous maps and figs.

During the spring and fall of 1940 an occasional travel-tattered straggler of the widespread butterfly *Hypolimnas bolina* L. was seen, but never more than a single one at a time, and separated by long intervals of time. By August 1941 this butterfly was abundant over the mile or so of island immediately south of the main channel leading from the lagoon into the sea. Strangely enough it occurs nowhere else on the island, despite the presence everywhere of Sida presumed to be the foodplant of its caterpillar. None of the other foodplants of Hypolimnas larvae recorded elsewhere occurs on Canton. The butterfly, the sexes of which are dimorphic, has several varieties, two of which have been seen on Canton. The establishment of Hypolimnas on Canton appears to be the direct result of the present abundant food supply in the form of Sida. A return to semi-arid conditions, with an attendant reduction of Sida foliage, would probably result in the sharp reduction of this insect's numbers, if not in its complete extinction.

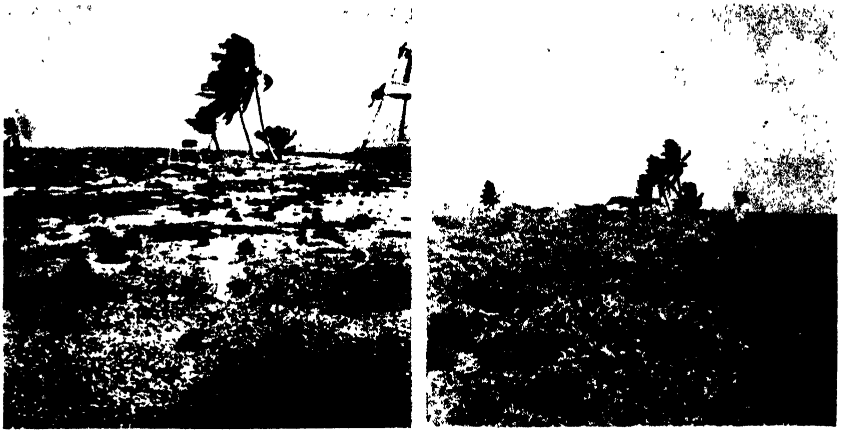

Fig. 1

Views taken on Canton Island two years apart showing contrast in vegetation (resulting mainly from growth of Sida) between a dry year and a wet one. The photograph on left taken by A. C. Browne in October 1939 (total rainfall for 1939, 18 inches); the other in September 1941 (1941 rainfall, through August, 84 inches). Both are looking northward.

The Monarch butterfly, *Danaida archippus* (Fabr.), has arrived singly at least once at Canton within the past year and a half,* but so far has not established itself there in spite of the presence, as a cultivated plant, of crown-flower, *Calotropis gigantea* R. Brown (family Asclepiadaceae), a favorite foodplant of its larva.

A conspicuous feature during the fall of 1941 was the large numbers in all parts of the island of the common "globe skimmer" dragonfly, *Pantala flavescens* (Fabr.), which was not seen at all on Canton the year before. Also present this year but not last, less numerous than Pantala, is the smaller, reddish dragonfly *Diplocodes bipunctata* (Brauer) ;† this species has been recorded from Australia and various Pacific islands including the Ellice group, Samoa, Tonga, Tahiti and New Caledonia. The presence of dragonflies on Canton this year can be traced to the formation and persistence of rain-fed pools, where immigrant individuals lay their eggs and in which their young can maintain themselves.

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* Reported in October 1940 by R. R. Danner.

† Both dragonflies were identified by Dr. F. X. Williams.

It seems probable that some or all of the above-mentioned insects, as well as others similarly capable of traveling long distances, have been established on Canton at one time or another in the past. The fact that the present establishment of the three discussed is recent suggests that conditions of food and water favorable for their maintenance are only temporary; that establishment and local extinction succeed each other as favorable and unfavorable conditions alternate; and that the present colonies of these particular species will in turn die out when severe drought recurs.

The prevailing winds at Canton are from the east or slightly south of east, seldom exceeding 25 miles per hour. Similarly, the principal ocean current is one moving westward along the equator. That the eastbound equatorial countercurrent also affects Canton appears doubtful. Currents apparently reach the island at times from the southeast, for a paddle found on the southwest coast is said by K. P. Emory, ethnologist of the Bishop Museum, to be of the southeastern Polynesian type (Society, Cook or Austral Islands). Pumice stones, obviously waterborne and not of local origin, are especially numerous on that part of Canton lying east of the lagoon. In 1941 for the first time, as far as is known, a few glass balls such as are used as fishnet floats by the Japanese were found on the beach at practically all cardinal points of the island. A piece of copal gum, showing evidence of having been afloat for a long time, was also found during the past summer. This is a secretion of certain leguminous trees, some of which occur in South America, others in Africa. To get information concerning the currents reaching the island, wood samples were taken from some of the numerous stranded trees to be found on both east and west coasts; these have not yet been identified.

Between December 1940 and February 1941 there were some weeks of strong westerly winds which attained a velocity of 55 knots. The effect of these prolonged gales on the normal ocean currents, though temporary, must have been considerable. Drift-borne seeds were absent or at least inconspicuous on the Canton beaches the year before, but by August 1941 they were a striking feature of the shore line everywhere. It is assumed that their presence is a result of the gales of the previous winter. Drift seeds collected were identified by E. L. Caum as follows:

Myristica sp. (Myristicaceae)
Entada scandens (L.) Bentham (Leguminosae-Mimosoideae)
Inocarpus edulis Forster (Leguminosae-Papilionateae)
Mucuna spp. (4) (Leguminosae-Papilionateae)
Caesalpinia crista L. (Leguminosae-Caesalpinioideae)
Canarium sp. (Burseraceae)
**Barringtonia speciosa* Forster (Lecythidaceae)
Terminalia catappa L. (Combretaceae)
Cerbera odollam Gaertner (Apocynaceae)
Unidentified spp. (3)

*** The nearest islands to Canton on which Barringtonia is known to occur are Samoa, the Wallis and Futuna group, and Fiji.**

In addition the writer identified seeds of the coconut[*] (*Cocos nucifera* L.), the kukui (*Aleurites moluccana* (L.) (Willdenow), and a hala (*Pandanus* sp.). The species named are all native or naturalized in Polynesia, as are also some species of Myristica, Mucuna, Canarium and Pandanus.

Seeds of many of the species listed had sprouted after stranding. Between 35 and 50 coconut sprouts were estimated to be still present in September along the entire 27-mile perimeter of the island, but these were only a small fraction of the total number of coconuts cast up. Some of the hazards attending the survival of seedling plants from drift seeds are obvious: hermit crabs (*Coenobita olivieri* Owen) shred the husks of coconuts and eat out the contents of the sprouted nuts; flood tides drench many seedlings with sea water; in at least one case high water buried a sprouted palm deep in sand. So the complete failure of any of the above-named plant species to become established on Canton in the past (all of the coconuts growing on the island are known to have been planted by man) is not surprising when, to the hazards already mentioned, are added the inevitable recurrent shortages of rain.

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[*] The nearest islands on which coconuts are growing, with their approximate distances in sea miles from Canton are: Enderbury 37, Sydney 100, Hull 120 and Gardner 190. Dr. C. H. Edmondson (Occ. Papers, Bernice P. Bishop Museum, 16: 293–304) recently tested the viability of coconuts after floating them in sea water for various lengths of time. In his experiments 110 days was the longest period in salt water after which coconuts still sprouted. "A conservative estimate of the distance that might be traversed in that time, if carried by a favorable current, is about 3000 miles."

Filter-Cake Compost

By J. P. Martin

The purpose of this article is to summarize the results of the investigations conducted on the rate of decomposition of filter cake under laboratory and field conditions and on the nutritive value of filter-cake compost. These studies were started January 1940 at the request of Dr. H. L. Lyon, and progress reports have appeared from time to time in the Director's Monthly Reports.

The value of humus or organic matter in the soil for securing normal plant growth has long been recognized. Humus is derived from plant and animal residues which are decomposed by microorganisms and is that residual portion of organic matter which undergoes little or no further decomposition. Humus in soils varies from about 0.5 to 12 per cent and is usually concentrated in the upper soil layer, and its presence in the soil is essential for maintaining the proper fertility level. It acts as a storehouse for nutrients upon which the plants and soil organisms draw during their development: it improves the tilth, moisture-holding capacity, and the chemical and physical properties of a soil. Sandy or clay soils are greatly improved by the addition of organic materials. Humus prevents rapid changes in the soil reaction to acidity and alkalinity, and it serves to neutralize toxic conditions in the soil. Humus improves the soil as a medium for those organisms which in turn convert raw materials into valuable plant nutrients.

Filter cake is a by-product of sugar production and is the filtered residue obtained from clarifying raw cane juices. It contains from about 8 to 10 per cent of finely divided fiber, 0.2 to 1 per cent sugar, 70 to 80 per cent moisture, and some nitrogen, phosphoric acid, potash, lime, and other mineral elements. It amounts to from 4 to 6 per cent of the weight of cane, that is, around 5 pounds of filter cake are obtained from 100 pounds of cane, thus showing that there is a very large amount of raw material to draw upon.

Filter cake is made up chiefly of plant residues, and during the process of decomposition the soil organisms assimilate large quantities of inorganic nitrogen and mineral elements, thus making these materials temporarily unavailable for growing crops. When decomposition reaches completion, large numbers of these organisms die and disintegrate and portions of the mineral elements become available for green plants. When undecomposed plant material such as fresh filter cake is applied to growing crops it becomes necessary to apply additional nutrients, otherwise the organisms will compete with the plants for nitrogen and other elements and the result is generally at the expense of the plants. Therefore it is advisable to compost plant residues from filter cake or cane trash outside the field and apply the compost later. The chemical nature of the final product depends largely on the original plant residues and on the rate and extent of their decomposition.

The most essential elements for rapid decomposition of filter cake by microorganisms are nitrogen, phosphorus, calcium, and potassium. Filter-cake compost, as the result of microbial decomposition, is reduced in volume and weight, and darkened in color. The organisms principally responsible for the rotting of filter cake are bacteria and fungi, which are low forms of plants devoid of chlorophyll, and which depend on other plants or plant materials for their livelihood. Many organisms are harmful while others are indispensable for the manufacture of animal and industrial products and for the final disposal by decomposition of all plant and animal materials.

Under favorable environmental conditions fresh filter cake is attacked immediately by organisms. The more important compounds attacked are as follows: carbohydrates such as sugars, starches, and cellulose, the latter being the fibrous material in the plant; proteins and their derivatives or the nitrogen-bearing constituents of the plant; fats and waxes; lignins, which are responsible for the stiffness or woodiness of plants; and mineral elements and various complex chemical compounds. Carbohydrates and some proteins decompose rapidly; cellulose, fats, and some nitrogenous substances decompose more slowly; while lignins, waxes, and resins are highly resistant to decomposition.

Laboratory Studies: For these studies 70 bags of fresh filter cake were secured from Oahu Sugar Company and the material spread on a large concrete platform, thoroughly mixed, and partially air-dried for three weeks. A composite sample of the partially air-dried material was collected and analyzed for certain constituents, the results of which are given in Table I under the heading of "Before Composting."

TABLE I

AN ANALYSIS* OF FILTER CAKE PRIOR TO AND AFTER COMPOSTING FOR SIX MONTHS AT MAKIKI

	Per cent (original basis)	
	Before composting	After composting
Moisture	68.39	68.36
Calcium, CaO	1.343	†
Potash, K_2O	0.145	†
Phosphate, P_2O_5	0.860	†
Total Nitrogen, N	0.367	0.49
Total Carbon, C	8.69	5.64
Carbon-nitrogen ratio, C/N	23.7 : 1	11.5 : 1

* Analysis by Chemistry Department.

† These nutrients would still be present after composting.

In studying the rate of decomposition of the fresh material, varying amounts of different fertilizers were added to and mixed with 100-pound portions of the partially air-dried filter cake. The filter cake used in the control series (with no fertilizers added) had a moisture content of 68.39 per cent, or 31.61 pounds of dry matter in each 100-pound portion. During the composting period, starting January 11, 1940 and ending August 2, 1940, each 100-pound portion in the treated and control series was held in a separate container. Frequent inspections of the filter cake in all series were made and sufficient moisture was added to maintain moist conditions at all times. After the filter cake had been composting for several months the material in each container was removed, examined, mixed, and replaced in its respective container.

On August 2, 1940, or within a little less than 7 months, the material in the control series was found to be thoroughly decomposed and at this time weights and moisture determinations of each container were recorded. The results are presented in Table II.

TABLE II

LOSS IN DRY WEIGHT OF FILTER CAKE AFTER COMPOSTING

Container	% moisture	Pounds of material		Difference in dry weights before (31.61 lbs.) and after composting
		Wet basis	Dry basis	
1	67.36	76.0	24.81	6.80
2	66.84	75.75	25.12	6.49
3	57.98	63.00	26.47	5.14
		Average....	25.47	6.14

It is thus shown that during the composting period there was a loss of 6.14 pounds or 19.42 per cent of dry matter. This difference may be accounted for by the release of gases (mainly carbon dioxide) which were formed by the microorganisms during the process of decomposition. In this series it was noted that the original volume was reduced to one half, the material was well decomposed, and that very little fiber from bagasse remained.

In other series it was noted that the rate of decomposition of the fresh material was not materially increased when additional fertilizers (chiefly nitrogen from ammonium sulphate) were added to the original material before composting.

In Table I the data show that the fresh filter cake before composting had a carbon-nitrogen ratio (C/N) of 23.7 : 1, while after decomposition the ratio was reduced to 11.5 : 1. Such a wide ratio as in the case of the former (23.7:1) would cause a nitrogen deficiency in plants. The organisms utilize many of the carbon compounds in filter cake as a source of energy as well as for structural purposes with the result that the carbon-nitrogen ratio is reduced. If this ratio becomes extremely narrow, for example 5 or 6 : 1, it indicates that large amounts of nitrogen have been accumulated.

Under laboratory and field (as shown later) conditions it was evident that fresh filter cake was thoroughly decomposed by microorganisms within 6 or 7 months and that it was adequately supplied with the necessary elements for the development of the organisms which were responsible for its decomposition. The fact that no additional fertilizers were essential for complete decomposition is of considerable economic importance when preparing the final product from filter cake which in itself is low in plant nutrients.

In pot experiments it was demonstrated that the fully decomposed filter-cake compost as prepared in the control series was an excellent medium for the growth of the following crops: tomato, corn, bean, beet, radish, and sugar cane (31–1389). In other pot studies it was shown that fresh or partly decomposed filter cake was definitely not suitable for the growth of the crops just mentioned.

Field Studies: During October 1940 a location was selected at Oahu Sugar Co., Ltd., by Mr. Hans L'Orange, where fresh filter cake from the mill could be hauled in order to study its decomposition under field conditions. Immediately following this date the plantation started and continued to haul filter cake for a period of several months, and at the end of the hauling period many hundreds of

Fig. 1. General view of filter cake being composted at Oahu Sugar Company.

Fig. 2. Lower edge of filter cake compost pile shown in Fig. 1.

tons of filter cake had been deposited in the compost pile. The site selected was along a railroad track where on one side the land sloped rapidly while on the other side there was less slope. With this arrangement the labor required for unloading the cars of fresh filter cake was reduced to a minimum. On November 13, 1940 the filter cake pile was examined and thereafter periodic examinations were made. On November 23, 1940 it was noted that where the filter cake was 5 or more feet in depth it had started to heat. On December 17, 1940 the heating of the filter cake was still in evidence and it was noted that decomposition had started in the upper surface foot; it was also observed that a heavy growth of mushrooms (chiefly *Coprinus atramentarius* and some *Agaricus campestris*, both of which are edible) had developed. Photographs of the filter-cake pile taken on this date by W. Twigg-Smith are shown in Figs. 1, 2, and 3.

A composite sample of fresh filter cake from the compost heap was collected December 17, 1940, and the results of the chemical analysis by the Chemistry Department follow:

	Per cent	
	Dry basis	Original basis
Moisture, H_2O	....	75.5
Calcium, CaO	0.78	.191
Potash, K_2O	0.252	.062
Phosphate, P_2O_5	4.31	1.056
Total nitrogen, N	1.22	.299
Total Carbon, C	33.77	8.27
Carbon-nitrogen, C/N	27.7:1	

These data show that the material (before composting) with its wide carbon-nitrogen ratio of 27.7 would be unsuitable for plant growth. It is recognized that the per cent of the various constituents, as reported above, will vary from time to time, but it was found that the fresh filter cake was adequately supplied with the necessary elements for the development of the organisms which were responsible for its decomposition. This was also the case when fresh filter cake was composted under laboratory conditions.

Under field conditions the filter cake was decomposed within from 5 to 7 months. In parts of the compost pile where the filter cake had been piled too deeply for the most rapid decomposition, the material on the bottom was not thoroughly rotted. It should be pointed out that abnormally dry weather conditions prevailed during the composting period and that no additional moisture was added. It is felt that the rate of decomposition would have been increased if normal rainfall had occurred.

The filter-cake compost prepared under field conditions at Oahu Sugar Co., when tested for its nutritive value on corn, (U.S.D.A. 34), eggplants (Black Beauty), beets (Asgrow Wonder), radishes (Early Scarlet Globe), and beans (Stringless Green Pod), was found to greatly stimulate the growth of all plants. In using filter-cake compost for vegetable culture it is suggested that the material be applied as a surface dressing and then worked into the soil before the seeds or plants are planted.

Filter-cake compost which is well decomposed is slowly transformed into humus. The organisms which cause fresh filter cake to rot require aerobic conditions, that is they require oxygen—humus is an aerobic product. Fresh filter cake should therefore be spread in layers not more than 3 to 5 feet in depth while it is undergoing decomposition. If fresh filter cake is piled too deeply anaerobic conditions are created, and organisms other than those under aerobic conditions develop and products, chiefly gases such as hydrogen, nitrogen, methane, carbon dioxide, carbon monoxide are formed. If possible it is advisable to turn the material over occasionally in order to insure a more rapid rate of decomposition. The material should be kept moist at all times; usually normal rainfall is sufficient to meet the moisture requirements. Under field conditions the material should be ready to use at the end of from 5 to 7 months.

Fig. 3. Mushrooms growing on the surface of the filter cake being composted at Oahu Sugar Company.

The decomposition of plant residues in the form of roots and stubble in gardens and cane fields adds large quantities of humus to the soil. Composting plant materials such as grass cuttings, leaves, entire plants, etc., is a common practice and a compost heap may be found in many gardens.

Acknowledgment: The writer greatly appreciates the cooperation received from Mr. L'Orange, manager, Oahu Sugar Company, Ltd., for furnishing the filter cake used in the laboratory studies and for conducting the field studies at Waipahu.

Are There Possibilities in Subsoil Fertilization?

By R. J. Borden

In his discussion "Why Root Studies?", W. P. Alexander (1) says "Plantation practice should emphasize the need of securing cane plants with the deepest root systems possible . . . . If root growth can be promoted in the lower depths our ratoons will be more stable . . . . Large cane yields are absolutely dependent on the right foundation of roots that are healthy and are expanded to the greatest extent."

Cane root studies by some investigators have shown evidence of well-developed root systems which extend especially into and also below the second foot of well-drained soils. Shaw (4), et al, in 1931 made field excavations at Waipio which revealed well-developed root systems of several cane varieties in the second foot of soil even at the early age of 3 months; and at 8 months, an excellent distribution was found even in the third foot of soil. Evans (2) studied a POJ 2878-Uba seedling which at 18 months had "roots in the second foot of soil that were nearly as numerous as those in the first foot," and many other varieties showed variable extents of root development below the first foot of soil. Jensen (3) found that although the roots in subsoils are fewer, they have longer and larger rootlets than surface roots.

Weller (5) presented evidence that a root showed greater branching when it came into the region of buried fertilizers. Evans (2) found evidence that the deeper roots from a harvested crop continue to function longer for the subsequent ratoon than the superficial or surface roots; furthermore that there is a tendency for this surface root system to become still more shallow as further ratoons are grown, and also that under conditions of drought the surface roots ceased to absorb nutrients, yet absorption of mineral substances by the deeper roots was continuous.

The opinion is rather well established that cane tonnages would be indirectly increased, as root systems are directly increased to provide larger root-feeding surfaces, from improved soil aeration. Wolters (6) found a marked correlation between root growth and top growth, and implied that the soil's textural and structural characteristics which govern aeration were responsible for root penetration. Evans (2) found a correlation coefficient of +.85 between root and top growth in monthly harvests of White Tanna, and believes that breaking up the subsoil promotes a deeper root growth, and attributes this to better aeration. The beneficial effect of tilling ratoons is assumed to be due to the opening-up of the soil and its better aeration. Jensen (3) presents evidence of shallow, retarded root growth where the soil is shallow and the subsoil impervious to air and water.

Although it is probably true that the formation oı instigation of secondary roots is dominated by aeration, their further growth and development will be of little extent unless adequate moisture and nutrients are available within the increased root-feeding zone. Thus tillage methods *alone* may not bring about the desired deep root penetration. Whereas the tillage operations presume to loosen the soil and let in more air and water, they also release some mineral nutrients which are important contributors to the increased root growth noted thereafter. Wolters (6, p. 78) tells us of a practice of hook-subsoiling which was at one time used by Oahu Sugar Company on the older ratoon fields, and he indicates that the better physical condition was responsible for its effectiveness. He says "Some of the old roots are ripped out, the soil is aerated and softened so that the fertilizer soon works into the root zone where it is readily and effectively utilized by the plant. The roots are stimulated by the presence of fertilizer, soon causing a rapid development into the loosened soil and later stimulating heavy stooling and shoot growth." We would be inclined to argue that the effectiveness noted was primarily due to the fact that the fertilizer got well down into the lower soil zones through the subsoil grooves.

It is doubtful if many soils of our cultivated fields actually lack oxygen in their second-foot layers, for we see very little evidence of slow drainage which would indicate inadequate pore space; the surplus water drains through rapidly, and air will follow this water. Thus it is unlikely that air itself has been a limiting factor in the root development of our sugar cane crops.

On the other hand it is a well-known fact that phosphates and nitrogen have had marked effects on root development. This is especially true of phosphate which promotes both root elongation and branching. The effect of nitrogen apparently is to inhibit root penetration and to promote profuse branching. Hence by our common field practice of applying nitrogen and phosphate on the surface soil, we tend to develop strong surface roots and to discourage the deep penetration of roots which is considered a more desirable type of root system. This common plantation practice of fertilization may be why some of our root studies have shown that only 30 per cent of the cane roots were found below the upper 8 inches of soil. What possibilities for increased yields, then, might we expect from deeper, more extensive cane root systems which would undoubtedly develop if the available nutrient levels in our subsoils were more nearly equal to those found in the surface soil?

The foregoing discussion is offered by way of an introduction to a consideration of data which have been gathered incidental to our testing, by the Mitscherlich method, of samples of soil from many of our cooperative field test areas during the past 10 years. These soil samples have come from widely scattered areas and were taken by many different individuals. To avoid the confusion which sometimes attends the identity of the actual point of differentiation between surface soils and subsoils in many of our cane lands, the samples were taken from each of two depths: those from 0–12″ were designated as surface soils, and those from 12″ to 24″ were called subsoils. A four-inch soil auger was used, and each soil sample was a composite from not less than 20 borings. Each sample was shipped to Makiki where it was air-dried just sufficient for screening and mixing. Subsequently it was potted, fertilized, and planted as follows:

No.	Identity	No. of pots	Root medium	Fertilizer			Indicator crop
				Gms. N	Gms. P_2O_5	Gms. K_2O	
1	No P_2O_5	2	Soil only	1.1	0	1.5	Panicum grass
2	N 6P K	2	" "	1.1	9.0	1.5	" "
3	No N	2	" "	0	9.0	1.5	" "
4	No K_2O	3	¼ soil; ¾ sand	1.1	3.0	0	Sudan grass
5	N 2P K	3	" "	1.1	3.0	1.5	" "

When the Sudan grass seed matured, all 12 pots were harvested and their dry weights secured. Due to seasonal variations, this maturity was usually reached between 70 and 90 days. Thus we have yields from surface soil and subsoil, each with and without P_2O_5, N, and K_2O, which can be set up for a comparison of the relative responses from each of these three nutrients.

Individual data are presented as a supplement in Table II, for such interest as they may have for the plantations concerned; they will not be discussed separately. But in Table I, we have summarized the results by Island groupings, and further discussion will relate to these data.

TABLE I

SUMMARY (True averages)

Identity of measurement and conditions	Soil depth	Hawaii	Kauai	Maui	Oahu	All Islands
1—Grams dry weight* without P_2O_5(1)	0–12″	117	109	167	180	126
" " " " "	12–24″	54	31	118	139	59
2—Grams dry weight* with P_2O_5(1)	0–12″	255	240	243	233	243
" " " " "	12–24″	252	233	237	225	237
3—% gain for P_2O_5	**0–12″**	**81**	**126**	**71**	**30**	**111**
" " " "	**12–24″**	**329**	**761**	**188**	**75**	**532**
4—Grams dry weight* without N(2)	0–12″	48	41	45	37	42
" " " " "	12–24″	28	23	28	28	25
5—Grams dry weight* with N(2)	0–12″	255	240	243	233	243
" " " " "	12–24″	252	233	237	225	237
6—% gain for N	**0–12″**	**521**	**497**	**528**	**544**	**513**
" " " "	**12–24″**	**943**	**918**	**757**	**722**	**885**
7—Grams dry weight† without K_2O(3)	0–12″	74	87	142	120	97
" " " " "	12–24″	74	63	125	103	80
8—Grams dry weight† with K_2O(3)	0–12″	108	129	156	136	129
" " " " "	12–24″	112	118	149	133	124
9—% gain for K_2O	**0–12″**	**47**	**51**	**11**	**14**	**40**
" " " "	**12–24″**	**52**	**94**	**20**	**30**	**66**

* Panicum grass.
† Sudan grass.
(1) With same N and K_2O.
(2) " " P_2O_5 and K_2O.
(3) " " N and P_2O_5.

Phosphate: When no phosphate fertilizer was applied, the average dry weight of panicum grass adequately fertilized with N and K_2O only, and grown on 166 subsoils, was approximately 53 per cent less than from the corresponding surface soils. Separately, the Kauai subsoils produced 72 per cent less than their surface soils, the Hawaii subsoils 54 per cent less, the Maui subsoils 30 per cent less, and

Oahu subsoils only 23 per cent less than their surface soils when no phosphate was applied. On the other hand, when both surface soils and subsoils were similarly and abundantly supplied with phosphate, there was less than 3 per cent difference in their respective yields. Thus it would appear that the phosphate fertilization of these subsoils was quite as effective as applications within the surface soils. If such an assumption can be made from these data, then we may infer that the effectiveness of phosphate fertilizer will not be diminished if it is placed in the subsoil root-feeding zones; and from our previous discussion we have reason to believe that it would be advantageous for deep root development to have the phosphate well below the surface layers of soil.

The figures showing the percentage gain from phosphate fertilization over no phosphate, on both the surface soils and subsoils, are interesting. Thus from the same amounts of P_2O_5 applied, the gains from subsoil fertilization were considerably greater than from surface soil applications. This was especially true of the Kauai and Hawaii soils and indicates the great differences which exist in the available phosphate supply of the two soil depths. Doesn't this suggest possibilities of better crops and more ratoons if we could build up the available phosphate supply of these subsoils and bring it somewhat nearer the levels in the surface soils?

Nitrogen: As was to be expected panicum grass yields, produced without nitrogen on soils taken from continually cropped cane fields, were generally quite low. The fact that the subsoils without N produced only about 60 per cent of the yields from the surface soils is in accordance with the usual finding that the available nitrogen supply in soils generally decreases with their depth. However, when supplied with identical amounts of nitrogen fertilizer (plus adequate P_2O_5 and K_2O), these subsoils were not significantly poorer than the surface soils in their ability to produce satisfactory crops.

The percentage gains in dry weights harvested, from the use of identical amounts of nitrogen fertilizer, were higher from the subsoils than from the surface soils, and as was the case with phosphate, this was especially true for the Kauai and Hawaii soils. Does this suggest the use of a material such as ammonium phosphate to be applied early in conjunction with a subsoiling operation that would allow this fertilizer to be put down, in the groove made by the subsoiler?

Potash: The dry weights of Sudan grass produced without potash were considerably less on both surface soils and subsoils from Kauai and Hawaii than from Maui and Oahu; this is in line with other data which have shown lower amounts of available potash in regions with heavier rainfall.

On the Hawaii soils when no potash was supplied, Sudan grass yields from subsoils were equal to the yields from surface soils, whereas with potash the yields from the subsoils were 10 per cent better than from surface soils. Without potash, the Kauai subsoils produced 30 per cent less than surface soils but only 9 per cent less when potash was supplied. The Maui and Oahu subsoils produced respectively 12 per cent and 14 per cent less than their corresponding surface soils without potash fertilizer, but less than a 5 per cent yield difference was obtained between these surface and subsoils where potash had been applied.

The percentage gain from a standard amount of potash applied to subsoils from Kauai, Maui, and Oahu was about twice that obtained from the surface soils, but there was little difference in this figure for the Hawaii soils. Apparently then there is less difference in the available potash levels between the surface soils and subsoils from the island of Hawaii than was found to be the case with phosphate or nitrogen; hence, subsoil fertilization with potash may not offer the same possibilities here which are indicated for these other two plant foods. But for the soils on the other three islands, there may be something gained by building up the available potash levels of the subsoils to a point somewhat nearer the surface-soil levels of this nutrient.

Conclusion: Granted that the data which have been recorded herein need a liberal interpretation, because the responses measured on both surface soils and subsoils were not actually obtained *in situ*, and with no attempt to minimize the effects from aeration which necessarily accompany all soil sampling, preparation and potting, yet we have shown that this aeration was in itself insufficient to make the subsoils produce satisfactory yields. Without N, or P_2O_5, or K_2O, there is only one instance (i.e., without K_2O in Hawaii soils) where the subsoils yielded as well as the surface soils; and certainly in the pot technique we have used, all soils were well aerated. On the other hand, well-fertilized subsoils have been made to produce yields which were not significantly different from similarly fertilized surface soils.

So the idea still persists that since few of our cane land soils really lack for air in their second-foot root zone, the failure of masses of roots to extend therein is chiefly due to a low available nutrient supply. If this condition can be corrected and this subsoil nutrient supply can be more nearly equalized with that of the surface soil, the desirable objective, cited by Alexander in our opening paragraph, should be easier to reach.

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SUPPLEMENT

TABLE II

AVERAGE GRAMS DRY WEIGHT HARVESTED

Plantation	No. of soils	Indicator crop = Panicum grass						No. of soils	Indicator crop=Sudan grass			
		Without P_2O_5		With N, P_2O_5 and K_2O		Without N			Without K_2O		With N, P_2O_5 and K_2O	
		Surface	Subsoil	Surface	Subsoil	Surface	Subsoil		Surface	Subsoil	Surface	Subsoil
HAWAII												
Waiakea	4	106	37	286	291	133	70	4	71	78	101	107
Hilo	1	164	70	309	282	25	13	3	74	80	157	148
Pepeekeo	4	93	22	244	231	28	18	4	77	81	107	115
Honomu	1	50	22	222	196	33	27	1	47	51	64	71
Hakalau	3	86	43	258	250	47	22	5	53	57	99	105
Kaiwiki	14	115	82	270	265	37	22	16	67	70	95	105
Hamakua	5	81	39	202	199	37	29	7	73	69	101	102
Paauhau	2	147	50	307	303	43	21	2	103	85	134	121
Haw'n Agr.	6	147	39	233	231	45	22	6	79	77	112	120
Hutchinson	5	156	55	254	259	44	27	6	94	81	124	120
Kohala	1	141	65	255	279	88	47	1	140	127	150	144
All Hawaii*	46	117	54	255	252	48	28	55	74	74	108	112
KAUAI												
Kilauea	13	64	24	225	223	43	21	25	62	42	116	107
Lihue	37	115	27	250	245	42	23	47	98	74	139	130
Grove Farm	15	120	23	239	225	37	23	22	94	58	141	121
Kipu	2	119	22	240	235	42	27	2	55	42	103	90
Koloa	4	145	44	272	265	59	33	5	110	88	145	131
McBryde	4	112	19	247	238	31	20	4	114	86	140	119
Kekaha	9	110	71	201	193	33	22	12	73	61	93	90
All Kauai*	84	109	31	240	233	41	23	117	87	63	129	118
MAUI												
Maui Agr.	2	157	77	213	208	33	26	8	141	126	155	148
H. C. & S.	3	167	110	203	215	24	21	12	142	127	150	144
Wailuku	4	211	189	235	234	40	29	13	148	133	158	152
Pioneer Mill	1	177	105	281	263	39	30	5	149	117	167	154
Kaeleku	2	81	37	328	293	102	39	2	89	82	143	159
All Maui*	12	167	118	243	237	45	28	40	142	125	156	149
OAHU												
Waimanalo	1	134	141	148	150	41	35	1	111	105	113	119
Kahuku	1	278	231	323	283	50	46	1	159	155	177	177
Waialua	4	156	76	232	229	45	32	4	118	92	138	139
Ewa	17	181	146	231	222	33	25	17	115	99	132	128
Waianae	1	211	166	270	287	55	40	1	173	155	186	163
All Oahu*	24	180	139	233	225	37	28	24	120	103	136	133

* True averages.

Boron in Some Hawaiian Soils and Crops*

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Only in comparatively recent years has it been generally recognized that boron is required by higher plants for normal growth. Today physiological disorders of some twenty-odd cultivated plants have been shown to be due to the lack of sufficient boron. The boron content of the soil solution and of irrigation water is usually relatively low; yet, if this concentration is increased by only a few parts per million, a condition which is toxic to many plants may arise. The range in concentration of boron at which normal growth takes place varies with the species of plant and is quite narrow for many. Hence, determining the amount of boron in soils and irrigation waters is of twofold importance from the standpoint of practical agriculture.

It was the purpose of this investigation to determine the distribution and amount of boron in soils, soil-forming materials, irrigation waters, and plants significant to Hawaiian agriculture.

METHODS OF ANALYSIS

All the boron analyses were made by the procedures proposed by Berger and Truog (1).

Water-soluble boron: The water-soluble or presumably available boron is extracted by boiling 20 gm. of soil with 40 cc. of water for 5 minutes and clarifying.

Total boron: The total boron is extracted from soils by a sodium carbonate fusion.

Boron in plant materials: The boron in the plant materials is determined after dry ashing and dissolving in dilute sulfuric acid.

DISTRIBUTION OF BORON IN HAWAIIAN SOILS

Horizontal distribution of boron:

This study of the distribution of boron in Hawaiian soils entailed a consideration of the amounts of total and water-soluble boron in different soils and also the vertical distribution in various soil horizons. Table I is presented to illustrate our findings concerning the distribution of boron in the various soil horizons. The profiles from Kona and Halemanu offer an interesting contrast between young and old soils, the former being younger than the latter. Both soils were formed under comparable conditions of rainfall and elevation. In general, the total boron content of the old surface soil is considerably higher than that of the younger soil. On the other hand, there appears to be a lower water-soluble boron concentration in the older soil. In all instances the total and water-soluble boron decrease with

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TABLE I

HORIZONTAL DISTRIBUTION OF TOTAL AND WATER-SOLUBLE BORON IN SOME HAWAIIAN SOILS

Soil No.	Origin of sample	Depth	Total boron p.p.m.	Water-soluble boron p.p.m.	Remarks
40–213a	Kona, Hawaii	0– 8"	14	0.9	Soil
40–214b	" "	8–16"	17	0.5	"
40–215c	" "	16–24"	13	0.4	"
40–215c_1	" "	16–24"	5	0.2	Partly decomposed aa lava
37–357a	Halemanu, Oahu	0–12"	46	0.7	Soil
b	" "	13–23"	14	0.3	"
c	" "	23–39"	6	0.2	"
d	" "	39–50"	3	0.2	Partly decomposed pahoehoe lava
e	" "	30'	2	0.2	Pahoehoe lava
37–401a	Maui Substation	0–10"		0.7	Soil
37–401b	" "	10–20"		0.2	"
40–217a	Ewa, Oahu	0– 8"		3.2	Soil
40–217b	" "	8–12"		1.8	"
40–316a	Manoa, Oahu	0– 6"		.6	Soil
b	" "	6–18"		.4	"
c	" "	18–30"		.2	"
40–419a	Hamakua, Hawaii	0– 8"		1.1	Soil
40–419b	" "	8–20"		.7	"
40–216	Kona, Hawaii		3	0.2	Aa lava
40–284	University Farm		3	0.2	Pahoehoe lava

depth, the parent materials always having the smallest amounts. The value of 3 p.p.m. of total boron in the two samples of Hawaiian lavas is in agreement with analysis of other igneous rocks reported (8).

Distribution of total boron in surface soils:

A study of the total boron in twelve representative surface soils showed a variation from 8 to 56 p.p.m. The old uneroded soils from the high rainfall districts were found to contain the greatest amounts of total boron, while the heavily eroded soils, the young soils, and the soils from the dry districts contained low amounts of total boron. The high amounts of total boron found in certain soils may be attributed to one or more of the following factors: (1) Concentration as a result of intensive weathering, (2) concentration by the continuous action of plants bringing boron from the lower horizons, (3) the fixation of boron added to the soil by rain water containing sea salts.

Distribution of water-soluble boron in surface soils:

Water-soluble boron was determined on 33 representative surface soils. It was found to range from 0.4 to 3.2 p.p.m. In those soils where both total and water-soluble boron were determined, there was usually more water-soluble boron in the soils containing low amounts of total boron. One major exception was an eroded surface soil from upper Manoa Valley which contained 0.4 p.p.m. water-soluble boron and 8 p.p.m. total boron. In general, the old acid soils from the high rainfall regions had the lowest amounts of water-soluble boron while the neutral soils from the dry areas had the highest.

Fig. 1 is a scatter diagram showing the relationship between soil pH and the amounts of water-soluble boron. This relationship is highly significant, the regression coefficient being 0.99 ± 0.17. However, this does not imply that the acidity of the soil caused the low amounts of available boron. Probably the soils which are acid have other properties which cause the low solubility of boron, measured by the procedure used.

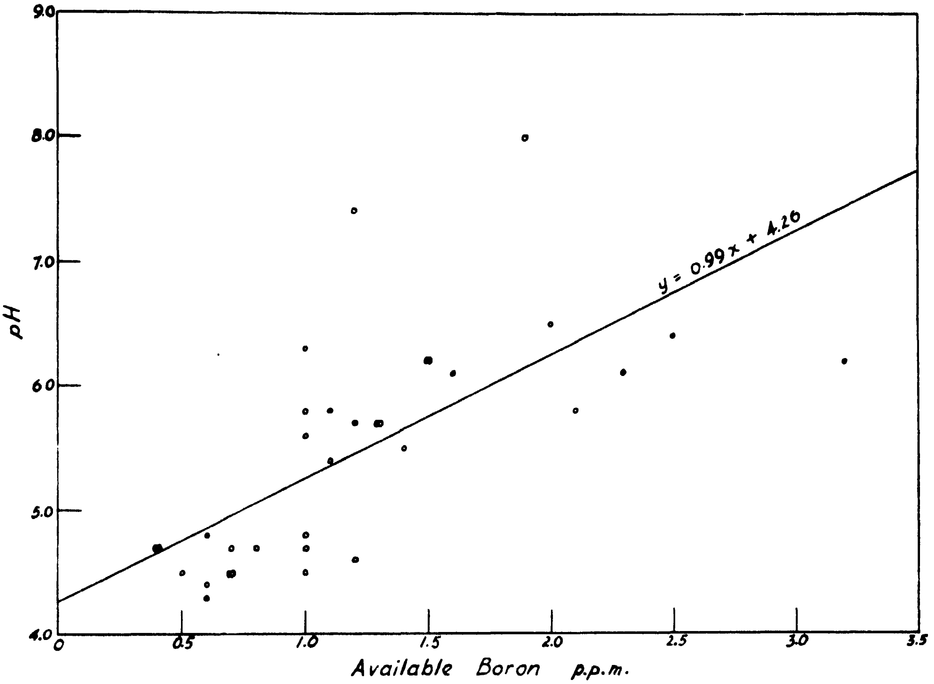

Fig. 1. Horizontal distribution of total and water-soluble boron in some Hawaiian soils.

Availability of Water-soluble Boron in Hawaiian Soils

A greenhouse investigation was undertaken to study the reactions of plants grown on Hawaiian soils having low amounts of water-soluble boron. Berger and Truog (2), working with Wisconsin soils have shown a good correlation between the water-soluble boron content of soils and the amounts of boron in the garden beets grown on them. They also found that the degree of black spot disease (a physiological disease caused by a lack of boron) was high in soils containing less than 0.7 p.p.m. of water-soluble boron. Ferguson and Wright (7) found that for the same soil type there was a relationship between the water-soluble boron of the soil and the amount of "apple cork disease."

The sunflower plant was selected as an indicator crop because its reactions to a boron deficiency have been described in detail (13). Three surface soils and one subsoil were selected because of their low water-soluble boron content. Each pot contained 400 gm. of soil and 5 sunflower seedlings. The treatments consisted of checks and 5 p.p.m. boron additions. All treatments were in triplicate. They were watered with distilled water except at weekly intervals when 25 cc. of nutrient solution containing 2.5 gm. N, 1.5 gm. P, 3 gm. K, 3 gm. Ca, and 1 gm. Mg per liter were applied.

Four weeks after planting, definite boron deficiency symptoms were apparent on the plants in untreated soils 40–316a and 40–316b. On the other hand, plants growing on the same soils, but receiving an application of 5 p.p.m. of boron showed no evidence of boron deficiency. In Table II are given the dry weights and the boron concentrations of the sunflower tops after 6 weeks of growth. With the exception of the plants grown on soil 39–463 there is an agreement between the composition of the plants and the water-soluble boron in the soil. The relation between plant weights and soil boron appears to be only a general trend. Soil 39–463 was very acid and infertile; consequently, factors other than boron deficiency probably limited plant growth and accounted for the lack of response to the low boron concentration of the soil.

TABLE II

WATER-SOLUBLE SOIL BORON IN RELATION TO THE GROWTH, DEFICIENCY SYMPTOMS AND BORON CONTENT OF SUNFLOWER SEEDLINGS

Soil No.	Available boron in soil	Boron added to soil	Average dry weight of tops	Boron in tops	Boron deficiency symptoms
	p.p.m.	p.p.m.	gms.	p.p.m.	
39–482	0.7	0	13.4	16	None
39–482	0.7	5	14.5	52	None
40–316a (0–6″)	0.6	0	12.3	11	Apparent
40–316a (0–6″)	0.6	5	15.1	34	None
40–316b (6–18″)	0.4	0	12.4	8	Apparent
40–316b (6–18″)	0.4	5	15.6	35	None
39–463	0.5	0	9.3	12	None
39–463	0.5	5	10.0	40	None

TABLE III

CONCENTRATIONS OF BORON FOUND IN HAWAIIAN WELL AND SEA WATERS

Source	Description	Boron
		p.p.m.
Koko Head	Well water	0.7
Waianae	" "	0.09
Ewa	" "	0.18
University Campus..................	Tap water	0.03
Near Shore	Sea water	3.6

Boron Fixation by Hawaiian Soils

When a solution containing boric acid, or borax, is brought in contact with certain soils, there is a tendency for the soil to fix or reduce the boron concentration of the solution. Eaton and Wilcox (6) have shown that the fixation of boron is of importance when irrigation waters contain large amounts of boron. For example, lemon trees grown on high boron-fixing soils showed less injury due to the application of high boron irrigation waters than those grown on soils with a low fixing power. Since the presence of toxic quantities of boron in a soil is most likely to occur as a result of using irrigation waters containing this element, it was of interest to examine certain Hawaiian waters. Table III gives the concentration of boron found in four well waters and in a sample of sea water collected near the shore. The sea water sample was lower in boron than the reported value of 4.5 for the Pacific (9) and 4.75 for the North Atlantic (11). The high amount of boron in the well water at Koko Head was undoubtedly a result of the mixing of sea and fresh water. The boron content of the other well waters was low in comparison with many of the natural waters found in California (12).

Some indications of the fixation of boron by Hawaiian soils were obtained from a study with an alluvial soil from Ewa (39–481) and a residual soil from mauka fields in Waipio (39–463). Twenty-gram soil samples and 100 ml. of solutions containing 0.25, 0.50 and 1.00 p.p.m. boron, as boric acid, were shaken in an end-over-end shaking machine for an hour. These suspensions were allowed to stand for 3 days and the boron concentrations of the supernatant liquids determined. The data obtained from these determinations are given in Table IV. It can be seen that the Waipio soil, which had a low level of water-soluble boron, fixed appreciable amounts of boron from a solution containing as little as 0.25 p.p.m.

TABLE IV

FIXATION OF BORON FROM SOLUTIONS OF VARIOUS CONCENTRATION

Soil	Soil pH	Boron concentration initial solution	Boron concentration final solution	Decrease in concentration of original solution
		p.p.m.	p.p.m.	per cent
Waipio	4.2	0	0.08	. .
39–463		0.25	0.20	20
		0.50	0.32	36
		1.00	0.68	32
Ewa	8.0	0	0.18	. .
39–481		0.25	0.25	0
		0.50	0.32	36
		1.00	0.55	45

TABLE V

THE EFFECT OF LIMING ON THE AVAILABILITY AND TOXICITY OF BORON

Liming Treatment	Boron added	Dry weight of tops	Boron concentration in tops	Total boron found in tops	Water-soluble boron in soil after harvest	Comments
	p.p.m.	gms.	p.p.m.	mgm.	p.p.m.	
Unlimed	0	14.7	28	0.41	0.5	Normal plants
Limed	0	19.0	23	0.44	0.4	Slight deficiency symptoms
Unlimed	2.5	14.9	100	1.49		Normal plants
Limed	2.5	20.0	92	1.84		Normal plants
Unlimed	10	15.8	200	3.16		Slight boron injury
Limed	10	19.8	150	2.97		Normal plants
Unlimed	25	16.1	360	5.80	4.2	Severe boron injury
Limed	25	21.6	250	5.40	5.3	Slight boron injury

On the other hand, the Ewa soil, which had a high level of water-soluble boron, fixed no boron from the lowest concentration; but, in contact with the highest concentration, it fixed more boron than the Waipio soil. The magnitude of fixation exhibited by these soils is of the same order as that reported by Eaton and Wilcox (6) for California soils. These workers have also shown that if a soil is dried while in contact with a boric acid solution an even greater fixation occurs. This would more nearly resemble field conditions.

Certain evidence has been presented by Naftel (10) and others showing that liming the soil causes boron starvation in some plants. Cook and Millar (5) effectively masked crop injury from excessive applications of boron by applying calcium and magnesium carbonates. There is no evidence, however, that calcium and magnesium carbonates fix boron in the soil.

An acid pineapple soil was selected for a pot series to show the effect of liming on boron availability and toxicity. The series included limed and unlimed soils which in one instance had received no boron and in others had received 2.5, 10, and 25 p.p.m. of boron as boric acid. All pots contained a kilogram of soil. The limed pots received 5 grams of C.P. calcium carbonate. All treatments were in triplicate, three sunflower seedlings were allowed to grow in each pot, and were harvested at the end of 6 weeks. The plants received distilled water and at weekly intervals 25 ml. of the nutrient solution previously described.

At the time of harvest the plants growing in the limed soil to which no boron had been added showed slight but definite boron deficiency symptoms, while the plants in the corresponding unlimed soil were normal. The plants grown on the limed soils which received 10 and 25 p.p.m. of boron showed no injury and slight injury, respectively, from the excessive amounts of boron. But, with the unlimed soils the injury was slight for the 10 p.p.m. and severe for the 25 p.p.m. applications. These observations seem to indicate that liming decreased the availability of the boron to the plant.

The dry weights of the sunflower plants (Table V) show in all instances an increased growth resulting from liming. There is no evidence that the boron treatment either increased or decreased the growth. The apparent injury to the leaves reported above was not reflected in the dry weights.

The boron concentration in the tops of the plants growing in the limed soils was always less than the corresponding unlimed ones (see Table V). However there was no important difference in the total amount of boron in the limed and unlimed plants. This indicates that the lime did not actually decrease the availability of boron in the soil, but did affect the actual concentration in the plant by promoting increased growth.

The amounts of water-soluble boron remaining in the soil treated with 25 p.p.m. of boron indicate considerable fixation of boron by the soil.

DISTRIBUTION OF BORON IN VARIOUS HAWAIIAN AGRICULTURAL CROPS

The amounts and distribution of boron in various species of plants vary greatly. Furthermore, the total absorption of boron by different species of plants in the same soil or culture solution may not be the same. Scofield and Wilcox (12) report a relationship between the boron content of orange tree leaves and that of the water supplied to them. Several boron analyses of various crops and plant parts are presented herein only as a matter of record. Their interpretation at present is of only general interest; however, they may become of interest if at some time it is advisable to continue this investigation of the role of boron in Hawaiian agriculture.

Sugar cane: Some indications of the amount and distribution of boron in the sugar cane plant were obtained from analyzing samples grown at the Kailua and Waipio substations of the Experiment Station, H.S.P.A., as well as in water cultures. These samples* from Waipio and Kailua were from 15-month old plant crops of 31–1389. The segregation into the various plant parts is the same as described by Clements (3). Two sets of water-culture samples were analyzed of which one was grown in a complete nutrient solution, while the other was grown in a minus-boron solution. These are the same plants as those reported on by Clements, Martin and Moriguchi (4).

The results of the boron analysis are shown in Table VI. Like most of the Gramineae, the sugar cane plant contains relatively low concentrations of boron, the highest concentrations being found in the meristem, elongating cane and leaf blades. In the absence of sufficient boron these parts also show the greatest decrease in concentration from the normal. The lower internodes, or millable cane, contain very small amounts of boron. It is estimated that a normal crop removes from the field less than 0.5 pound of boron per acre.

Pineapples: The distribution of boron was determined in two sets of pineapple plants, one from Oahu and the other from Kauai. The Oahu plants were grown in a soil containing 1.0 p.p.m. of water-soluble boron, whereas the Kauai pineapple soil cointained only 0.4 p.p.m. Both sets of plants were divided into groups of comparable physiological age.

The boron analysis of the pineapple plant samples is presented in Table VII.

TABLE VI

DISTRIBUTION OF BORON (P.P.M. IN DRIED TISSUE) IN SUGAR CANE GROWN AT KAILUA, WAIPIO, AND IN NUTRIENT SOLUTIONS

Plant part	At Kailua substation	At Waipio substation	In complete nutrient solution	In Minus—boron nutrient solution
Spindle cluster	3.2	4.8	4.9	1.3
Leaf blades, elongating cane	3.6	3.5	11.0	2.4
" " green-leaf cane	3.2	7.0	11.0	
Leaf sheaths, elongating cane	1.9	2.1	3.6	1.4
" " green-leaf cane	1.6	1.6	3.2	
Meristem	9.5	9.5	9.0	3.1
Elongating cane	7.0	5.5		
Green-leaf cane	1.5	1.6	2.4	
Top internodes	1.0	1.0	1.6	1.0
Next three internodes	1.2	1.1	1.1	1.0
" " "	1.0	0.8	0.9	.5
" " "	0.8	0.6	0.7	
All other internodes	<0.5	<0.5		
Water-soluble boron in soil	0.8	1.8		

These samples were supplied through the courtesy of the Division of Plant Physiology.

TABLE VII

THE DISTRIBUTION OF BORON IN PINEAPPLE PLANTS

(p.p.m. in dried tissue)

OAHU PLANTS		KAUAI PLANTS	
Plant part	Boron content	Plant part	boron content
	p.p.m.		p.p.m.
"C" Leaves, white basal	7	"C" Leaves, white basal	4
" " central	18	" " central and tips	15
" " tips	36		
"D" Leaves, white basal	10		
" " central	17		
" " tips	24		
"E" Leaves, white basal	7	"D, E and F" Leaves, white basal	7.0
" " central	9	"D, E and F" Leaves, central and tips	9.0
" " tips	13		
"F" Leaves	6		
Growing point	9	Growing point	5.5
Water-soluble boron in soil	1.0	Water-soluble boron in soil	0.4

"C"—Fully grown leaves at an angle greater than 45° from vertical.
"D"—Leaves at an angle of 30–45° from vertical.
"E"—Leaves more than a foot in length and less than 30° from vertical.
"F"—Remaining leaves and leaf primordia.

TABLE VIII

BORON CONTENT OF MISCELLANEOUS CROPS GROWN WITH AND WITHOUT THE USE OF BORON AS A FERTILIZER.

(p.p.m. in dried tissue)

Plant	Plant part	Boron content	Comments	
		p.p.m.		
Radish	Tops	34	Pot culture—0.7 p.p.m. H_2O soluble soil B	
"	Roots	25	" " " " " "	
"	Tops	72	" " " " " "	3 p.p.m. B added
"	Roots	30	" " " " " "	" " "
Beet (table)	Tops	32	" " " " " "	
" "	"	20	" " " " " "	$CaCO_3$ added
" "	"	73	" " " " " "	3 p.p.m. B added
Tomato	Tops	14	" " " " " "	
"	"	26	" " " " " "	3 p.p.m. B added
Coffee tree	Leaves (young)	52	1.0 p.p.m. H_2O soluble soil B	
"	" (old)	76	" " " "	
"	Leaves (young)	80	1.0 p.p.m. H_2O soluble soil B trees fertilized with B	
"	" (old)	156	" " " " " " " "	

These data show the highest concentration of boron to be in the older plant parts such as the leaf tips. The meristematic regions, that is, white basal leaf tissue and the growing points, were comparatively low in boron. The plants growing in the low boron soil contained less boron than the ones from the soil with high boron. The older leaf parts (tips and central sections) showed the most marked decrease in concentration due to low amount of water-soluble boron.

Miscellaneous crops: Radish, beet and tomato seedlings were grown in a pot culture series, using the same soil (Manoa 39–482), both with and without the additions of boron. The boron content of the plant materials harvested from this experiment was determined and the results shown in Table VIII. These data show the radish and beet tops to have about the same concentration of boron. The tomato tops, on the other hand, showed a considerably lower concentration. The addition of 3 p.p.m. of boron to the soil approximately doubled the concentration of boron in the tops of all the three plants.

Leaf samples were collected from coffee trees growing in Kona, Hawaii. Some of the trees had received 6 pounds of boron per acre annually for two years prior to sampling. The boron analysis of these samples is given in Table VIII. The young leaves were approximately 3 months old at the time of sampling, while the old leaves were a year older than the young ones. These results show a definite accumulation of boron in the older leaves. There was a marked increase in the amounts of boron in the leaves of the trees fertilized with boron.

SUMMARY

This paper on the boron status of Hawaiian soils gives consideration to: (a) The distribution of total and water-soluble boron, (b) the availability of water-soluble boron, (c) the fixation of boron, and (d) the boron content of various agricultural crops. The results may be summarized as follows:

(1) The total boron was found to be highest in surface soils—4 to 56 p.p.m. The old uneroded soils from regions of heavy rainfall have the most total boron.

(2) The water-soluble boron was highest in surface soils and varied from 0.4 to 3.2 p.p.m. Generally, the soils with high total boron had a low water-soluble boron content. A significant relationship was found between soil pH and water-soluble boron content.

(3) It was demonstrated that certain Hawaiian soils have the property of fixing boron from dilute solutions of boric acid.

(4) The distribution of boron in the various organs of sugar cane and pineapple plants was determined and presented. A normal crop of sugar cane removes from the soil less than 0.5 pound of boron per acre.

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" " tips	36		
"D" Leaves, white basal	10		
" " central	17		
" " tips	24		
"E" Leaves, white basal	7	"D, E and F" Leaves, white basal	7.0
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BORON CONTENT OF MISCELLANEOUS CROPS GROWN WITH AND WITHOUT THE USE OF BORON AS A FERTILIZER.

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Rainfall Evaluation as an Aid to Irrigation Interval Control

By J. A. SWEZEY

Rainfall can range in effect from a menace to life and property, when it is of cloudburst proportions, to a mere insignificant and ignored "trace" on the records of a weather station. Depending upon the moisture content of the soil just prior to a rain, the amount and to a certain extent the intensity of the precipitation, rainfall can be as great a boon to agricultural projects as a full or partial irrigation.

The evaluation of normal amounts of rainfall as supplementary irrigations on Hawaiian sugar cane lands has been for years attained by individual judgment, and has been influenced largely by personal considerations. In general, the estimated degree of credit allowed any rainfall was on the conservative side of not attempting to claim as much benefit for the rain as it may actually have been worth. This was never satisfactory to the sugar planter, for he would have liked to improve irrigation efficiency by claiming more nearly the full credit for a rain, as well as to have been freed of the uncertainty attached to a conjectured estimate of the rain's effectiveness.

In recent years studies of soil moisture and cane growth relationships have indicated that a program of regular, routine soil-moisture observations could be expected to provide information relative to the length of the irrigation interval, *i.e.*, the elapsed time between successive irrigations which would furnish the cane plant with water at the most efficient frequencies on a basis of the commercial product (3), (6), (7). Such a soil-moisture observation program would also reveal directly the effect of any rainfall upon the extension of the irrigation interval, with a resultant increase in efficiency.

The late Dr. U. K. Das, in 1936 (1), suggested the use of day-degrees as a measure of the irrigation requirements of the sugar cane plant. In developing this proposed utilization of day-degrees, he recognized rainfall as a factor which would have to be evaluated in order to properly operate an irrigation control based on day-degrees. We quote from Dr. Das' paper:

"How to adjust for rainfall? In the arid or semi-arid districts like Waianae or Ewa an inch of rainfall may be considered as equal to one-tenth of an irrigation (*i.e.*, ten per cent of the area irrigated). This value may be somewhat different in different places. However, once we have decided from experimental or observational data what value to give to rainfall, we can take that into account in determining when to apply the next irrigation. In general it may be advisable to underestimate rather than overestimate the value of scattered showers."

PRELIMINARY ATTEMPTS

In September 1939 at Waipio a rain of 1.54 inches in a 24-hour period fell on the 32 plots of Experiment 104-I. These plots had a considerable variation in their soil moisture contents at the start of the rain. An opportunity was thus afforded to analyze the effect of this rain toward replenishing soil moistures under the various existing conditions. From such an analysis a set of curves, one for each 0.1-inch increment of rainfall, was derived which would correct an irrigation interval for such rainfall as might occur at any time between scheduled irrigations. The elapsing interval and the correction for rainfall were expressed in day-degrees, so as to take advantage of this suggested method of gauging intervals. The correction was to be deducted from the elapsed interval.

These corrections were offered in the forms of curves and tables to a number of plantations for trial (4). It was recognized that, being based on the effects of a single rain, the corrections were subject to a probable wide margin of error, and that they would suffice only as a partial help in allowing for rain. The collaborators were so advised.

During 1940 a study of available cane growth, soil moisture, rainfall, and day-degree records from Experiment 138-I at Waialua resulted in the derivation of a second set of curves and tables for rainfall evaluation (5). These were released in January 1941 in the belief that they were developed on a much sounder basis than the first tables, since many observations were used of various amounts of rain falling on soil with a wide range of moisture contents prior to each rain. These tables seemed quite acceptable for some conditions, but on the rainy side of Kauai they appeared to account inadequately for continuous small rains.

In March 1941 a study of data from Experiment 104-I harvested early in 1941 at Waipio produced a third set of adjustments for rainfall. These were discussed before several seminar groups composed respectively of the staff of the Experiment Station and the staffs of various plantations on Oahu and Kauai. It was hoped that the discussions would reveal any errors or omissions, inherent in the new tables, and would indicate from the opinion of field experience the necessary rectifications. The seminars proved to be most helpful, especially those conducted at individual plantations where a variety of specific problems (soil depth, moisture-holding capacity, wind effect, cane variety, etc.) was brought to our attention. As was expected, the new adjustments were found to be fallible in some respects, even within the rough limits of field usage. All who participated in the seminars, however, believed that the tables could be revised to account for the suggested weaknesses. One major criticism was that they were not properly applicable to shallow soils. Another objection was that there was a discrepancy in the amount of day-degrees from irrigation to wilting point between the second and the third set of curves. Due to these objections and others of a minor nature this third set of curves was not released.

It should be stated that each of these curves was used in turn at Waipio with no disastrous results. However, there were infrequent rains of small consequence during their two-year use.

EVOLUTION OF PRESENT RAIN EVALUATION TABLES

Personal discussions with mainland investigators and papers offered at the June 1941 meetings of the Western Society of Soil Science (9), together with a reconsideration of the data in Experiments 138-I and 104-I, have resulted in a revised perspective in approaching the problem of adjusting irrigation intervals for rainfall. This paper will present a group of adjustments based on this latest interpretation of the relationships between sugar production, soil moisture, and the value of rainfall, and will describe how these new adjustments are used at Waipio to regulate the scheduled irrigation intervals in accordance with rainfall received.

The first three sets of rainfall tables which were devised were based on a single depth of root zone (34 inches), and on a single 8 per cent available soil-moisture capacity (8 per cent from maximum field capacity to first wilting point), and using H 109 cane. Seminar discussions indicated that a means of accounting for a number of different soil conditions and situations would be necessary to allow satisfactorily for rains according to the general method proposed with the adjustment tables. In order to avoid presenting too many tables, which by their bulkiness would prove too cumbersome for practical field use, it was decided to devise a table of adjustments for each of three levels (high, medium, and low) of the two factors of soil conditions involved. Therefore, nine specific tables are presented on the following bases:

Table no.	Approximate depth of root zone (inches)	Range of moisture equivalent (per cent)	Average corresponding available soil moisture (P_{fwp}) (per cent)
I	34	36–50	11
II	34	25–36	8
III	34	12–25	5
IV	23	36–50	11
V	23	25–36	8
VI	23	12–25	5
VII	11	36–50	11
VIII	11	25–36	8
IX	11	12–25	5

DETERMINATION OF SOIL-MOISTURE EXTRACTION CURVES

The first step necessary in deriving the tables was to find how many day-degrees should be expected to accumulate, *with no interference from rainfall*, between the day of irrigation and the day on which the "first permanent wilting point" was reached in the soil moisture. To determine this amount of day-degrees, detailed studies of the rates of soil moisture extraction in Experiment 104-I (Waipio) were analyzed statistically. Fig. 1 shows how the rates of soil moisture extraction were determined. The case used is from actual observations in Experiment 104-I, Plot 2-A.

The plot was irrigated on June 14 and a series of soil moisture observations from June 17 to June 24 inclusive produced an irregular extraction curve. During the day ending at 6 a. m., June 25, a rain of 0.21 inch was received. A series of samples taken from June 25 to July 3 inclusive also showed some irregularity, but all samples were at or below the wilting point. H 109 cane growth is seen to have proceeded at a rapid rate from June 14 to June 27 inclusive, after which the growth rate was retarded. Another irrigation was applied on July 5, and was followed by an increase in the rate of cane growth.

The single irrigation cycle, or interval, thus described may be interpreted as follows:

We have laid a straight edge on the soil-moisture observations of June 17 to 24, and moved it about to obtain the best fit to the plotted points. A dashed line is drawn to define this fit, and it represents the probable rate of extracting moisture from this soil by the cane crop. There is no reason to suspect that the extraction rate between June 14 and 17 would be materially different from the rate obtained

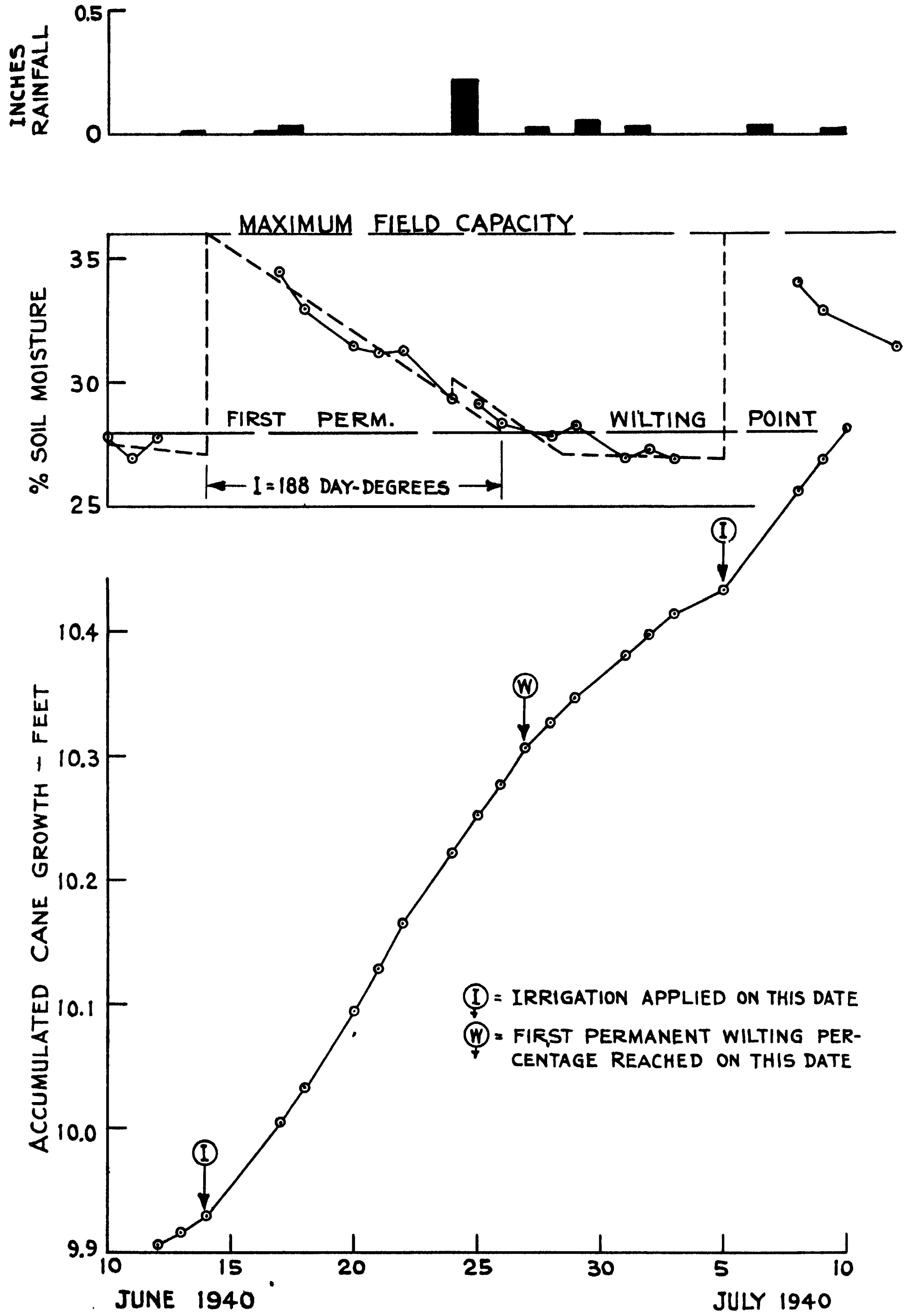


Fig. 1. Sample of graphical records of soil moisture, H 109 cane growth, and rainfall data for Plot 2-A of Waipio Experiment 104-I. (This shows the method of determining rates of soil-moisture extraction in terms of day-degrees.)

by the observations taken between June 17 and 24. Therefore we have extended the dashed line to the left to intersect the maximum field capacity on June 14, the day of irrigation. Likewise this line is extended to the right to intersect the first wilting point on June 26. In other words, if the rate of soil-moisture extraction, which is indicated by soil samples to have prevailed between June 17 and 24, is considered to be representative of the probable uninterrupted period of time from field capacity to the wilting point, then this period was from June 14 to June 26. The weather data showed that 188 day-degrees were accumulated between these dates. This period of extraction of readily available soil moisture is termed "I." Similar interpretations were made for all possible cases to be found in the experiment and a large number of values in day-degrees were obtained for "I."

Notice that our interpretation of the soil-moisture data shows that the wilting point was actually reached on June 27, not on the 26th. This is verified by the slowing of the cane growth after June 27, and is without doubt due to the 0.21 inch of rain falling between June 24 and 25.

A statistical analysis of many rates of soil-moisture extraction thus determined gave the following results:

In Experiment 104-I at Waipio it was found that 808 observations of rates of soil-moisture extraction by the sugar cane plant gave a true mean of 175.9 day-degrees from the date of irrigation to the date on which soil moisture would be expected to reach the first permanent wilting point. The probable error of this mean was ±0.77 day-degree, and the probable error of any single observation was ±21.8 day-degrees. The probable error of a single observation is the important figure to inspect. In experiment 104-I it is 12.4 per cent of the mean. The expected error of a single interval that might be applied is therefore within the variability of field practice in applying irrigation intervals. For example, if a 15-day interval is scheduled for a field and the water is applied on the 17th day, or two days late, the irrigation is late by 13.4 per cent of the scheduled interval. In many actual cases irrigations are even more than two days late, due to any of a number of causes. Hence the interval of 175.9 day-degrees might be considered satisfactorily reliable as a basis upon which to start developing curves for interval adjustments.

For the benefit of those readers who are mathematically inclined, it will now be necessary to inflict some symbols and calculations on other readers, in order that the derivation of these adjustments will be clearly understandable.

The soil of Experiment 104-I is identical with the conditions cited for Interval Adjustment Table II, *i.e.*, 8 per cent soil moisture above the first wilting point available to the cane in a 34-inch deep root zone.

Referring to the nomenclature in Appendix I, and using the Equation No. 2 which expresses the manner in which soil is saturated by water applied on the surface, the following relationships are found for this soil:

$MFC = 36\%$
$FWP = 28\%$
$V = 1.1$
$d = 34$ inches
$I = 175.9$ day-degrees
$R = ?$

$$P_{fwp} = \frac{MFC - FWP}{100} = \frac{8\%}{100} = 0.08$$

$$D = P_{fwp} \times V \times d = 0.08 \times 1.1 \times 34 = 2.99 \text{ inches of water.}$$

Equation No. 3 gives the soil-moisture extraction rate:

$$R = \frac{I}{D} = \frac{175.9}{2.99} = 58.8 \text{ day-degrees per inch of water.}$$

The significance of the value of R is that when 58.8 day-degrees have been accumulated from the date of an irrigation, it can be expected that 1 acre-inch per acre of water has been taken from the soil by the cane crop.

The ideal soil-moisture extraction curve for the Waipio soil appears in Fig. 2. This shows a straight sloping line descending from 8 per cent soil moisture available at 0 elapsed day-degrees to 0 per cent available moisture at first permanent wilting point, which occurs at 176 elapsed day-degrees.

The soil-moisture extraction curves for the other 8 combinations of soil depths and available moisture capacities were derived as follows:

Combining the equations for D and R given above, we have:

$$R = I/D = \frac{I}{P_{fwp} \times V \times d}$$ in which R is presumed to have the same value in all cases (58.8 day-degrees per inch of water).

Therefore: $I = R \times P_{fwp} \times V \times d$

This equation was used, then, for the remaining 8 cases:

Case I:

$P_{fwp} = 11\% = 0.11$ $\quad R = 58.8$
$d = 34$ inches $\quad V = 1.1$
$I = 58.8 \times 0.11 \times 1.1 \times 34 = 241.9$ day-degrees. $\quad I = ?$

Case II:

This was obtained by measurements in the field (Expt. 104-I) and has been given above, *i.e.*, $I = 175.9$ day-degrees.

Case III:

$P_{fwp} = 5\% = 0.05$ $\quad R = 58.8$
$d = 34$ inches $\quad V = 1.1$
$I = 58.8 \times 0.05 \times 1.1 \times 34 = 110.0$ day-degrees. $\quad I = ?$

Case IV:

$P_{fwp} = 11\%$ $\quad R = 58.8$
$d = 23$ inches $\quad V = 1.1$
$I = 58.8 \times 0.11 \times 1.1 \times 23 = 163.6$ day-degrees. $\quad I = ?$

Case V:

$P_{fwp} = 8\%$ $\quad R = 58.8$
$d = 23$ inches $\quad I = ?$
$I = 58.8 \times 0.08 \times 1.1 \times 23 = 119.0$ day-degrees. $\quad V = 1.1$

Case VI:

$P_{fwp} = 5\%$ $\quad R = 58.8$
$d = 23$ inches $\quad V = 1.1$
$I = 58.8 \times 0.05 \times 1.1 \times 23 = 74.4$ day-degrees. $\quad I = ?$

Case VII:

$P_{fwp} = 11\%$ $\quad R = 58.8$
$d = 11$ inches $\quad V = 1.1$
$I = 58.8 \times 0.11 \times 1.1 \times 11 = 78.3$ day-degrees. $\quad I = ?$

Case VIII:

$P_{fwp} = 8\%$ $\quad R = 58.8$
$d = 11$ inches $\quad V = 1.1$
$I = 58.8 \times 0.08 \times 1.1 \times 11 = 56.9$ day-degrees. $\quad I = ?$

Case IX:

$P_{fwp} = 5\%$ $\quad R = 58.8$
$d = 11$ inches $\quad V = 1.1$
$I = 58.8 \times 0.05 \times 1.1 \times 11 = 35.6$ day-degrees. $\quad I = ?$

It is interesting to compare the rate of soil-moisture extraction by H 109 cane from Experiment 104-I at Waipio with that found in Experiment 138-I at Waialua. In the latter experiment it was found that 986 observations of rates of soil-moisture extraction gave a true mean of 131.0 day-degrees between the date of irrigation and the date on which soil moisture reached the first permanent wilting point. The probable error of this mean was ±0.59 day-degree, and the probable error of any single observation was ±18.4 day-degrees.

The value for R in the Waialua test is found to be 62.1, as follows:

$$P_{twp} = \frac{MFC - FWP}{100} = \frac{8\%}{100} = 0.08 \qquad I = 131.0 \text{ day-degrees}$$

$$d = 24 \text{ inches} \qquad V = 1.1 \qquad R = ?$$

$$R = I/D = \frac{I}{P_{twp} \times V \times d} = \frac{131.0}{0.08 \times 1.1 \times 24} = 62.1 \text{ day-degrees per inch of water extracted.}$$

This is close to the value (58.8) found at Waipio, and tends to indicate that the rate of extraction of soil moisture in two widely separated localities can be measured by the common index—the day-degree. True, this is only one comparison, but it should serve to stimulate interest toward obtaining additional comparisons.

The reason why there is a difference between Waialua and Waipio in the number of day-degrees between an irrigation and the date on which soil moisture reached the first wilting point is that at Waipio there was a root zone at least 34 inches in depth, whereas in the Waialua experiment we are certain that a hard pan limited the effective root zone to a depth of about 24 inches. It is only natural that the wilting point would be reached sooner in the Waialua experiment, there being less total water per acre available after irrigation due to the shallower root zone. Previously we had neglected to consider the difference in depth of root zones between these two sets of data.

From the values of P_{twp} and the corresponding values of I calculated above, soil-moisture extraction curves for our 9 cases were obtained and plotted in Figs. 3 through 11; see Appendix II.

On all of these graphs showing the soil-moisture extraction, it is seen that the curves extend beyond the first permanent wilting point to a soil-moisture value 2 per cent below the first permanent wilting point, and remain constant from there on. This lower level of moisture is termed the "ultimate permanent wilting point." It is used in these graphs because the soil-moisture data obtained from both experiments mentioned above show that the cane plant actually extracted from two to four per cent of moisture below the first permanent wilting point.

WILTING POINT VS. WILTING RANGE

Reference to two permanent wilting points, first and ultimate, may be somewhat confusing to the reader, since in recent years there has been an increasing tendency in Hawaii to apply only the one term "permanent wilting point or percentage" to designate the lower limit of soil moisture available to the cane plant. An explanation, and revision of our ideas regarding wilting is necessary at this stage of our soil-moisture investigations.

We have come to presume that the "permanent wilting point" of a given soil is at a specific percentage, and have stressed this amount as the lower limit of soil moisture readily available to the plant for the promotion of a normal rate of growth. Even though the first decrease in growth rate was relatively slight when this specific point was reached, and further moisture was extracted before the growth rate became severely handicapped, still the reduction in the rate of elongation was accepted as a commercial loss. Hence, the probable existence of a wilting range was subordinated to the concept of that moisture content at which the first departure from rapid growth occurred as being the all-important and critical limit of availability. It is true that our literature does mention a wilting zone or range, yet the tenor of these comments definitely attaches major importance to the upper edge of that zone as more critical than the lower.

Subsequent experiments, well-replicated and carefully operated, have shown that soil moisture is actually extracted by the H 109 cane to a level which is 2 to 4 per cent below that formerly described as the permanent wilting percentage. Observations in these experiments indicated that except for a reduction of growth rate, no visible distress was manifested by the cane during the time this additional 2 to 4 per cent moisture was being extracted. A reduction of cane tonnage resulted from repeatedly withholding irrigations until some time after "permanent wilting percentage" was passed, but this was no commercial loss, since the sugar yield was not reduced and the cost of irrigation was lessened (6), (7). It would seem that allowing soil moisture to fall below the "permanent wilting percentage" to a still lower limit, at which soil moisture became in fact totally unavailable, was not destructive to the commercial yield from the field.

Apparently, therefore, the "permanent wilting percentage" as we have used it is what the mainland investigators in recent years have termed the "first permanent wilting point." Some physiological reaction in the cane plant undoubtedly commences when soil moisture reaches this level, but the plant continues to obtain additional moisture from soil that is depleted to a still lower level, which these same investigators term the "ultimate permanent wilting point," and at which soil moisture then becomes unavailable. Thereafter, an injurious effect on the plant's physiological processes develops with increasingly acute severity unless soil moisture is replenished within a reasonable time (2), (8). Our experiments have given some indications of the length of this time.

The opinion of mainland soil scientists regarding wilting is capably reviewed in recent papers by J. R. Furr and C. A. Taylor of the U. S. D. A. at Pomona, California (2), (8). In discussions with Drs. Furr, F. J. Veihmeyer and A. H. Hendrickson of the University of California at Davis, California, and G. E. P. Smith of the University of Arizona, this opinion was stated personally. It may be summarized briefly as follows:

(1) Wilting does not occur necessarily at a definite precise level of per cent soil moisture. The above investigators invariably refer to a "wilting range."

(2) The first, but more or less unimportant, signs of wilt appear at the "first permanent wilting point."

(3) The "ultimate permanent wilting point" is the lowest limit of soil moisture extractable by the plant, and is the critical moisture content relative to the plant's physiology.

DERIVATION OF INTERVAL ADJUSTMENT TABLES FROM SOIL-MOISTURE EXTRACTION CURVES

In our consideration of the problems of the moisture conditions of the soil and the reactions of the cane to these conditions, we have not lost sight of the fact that even after moisture has been extracted to the ultimate wilting point in the surface root zone, there are still a number of long tap roots which probably supply the plant with some moisture for an additional period of time. This moisture is of partial benefit to the plant, and undoubtedly can complicate the evaluation of the relationships of rainfall, soil moisture, and plant reaction, but for the present, practical considerations dictate that it be disregarded.

Using the soil-moisture extraction curves, it is possible to obtain curves to adjust the irrigation interval for various amounts of rain. Actually the adjustments are supplied in tabular form, but the method of computing the tabular values will be explained graphically using Case II, the Waipio soil with 8 per cent soil moisture (P_{fwp}) available to the cane, and a 34-inch depth of root zone.

In this case, and all others, the per cent moisture available to the plant is to be understood to mean the difference in per cent moisture between maximum field capacity and the first wilting point. The reason for this is that the first wilting point can be detected far more readily in the field than the ultimate wilting point. The first wilting point, having been checked for number of day-degrees after irrigation, determined the rate of soil-moisture extraction (R). The ultimate permanent wilting point in terms of day-degrees could then be fixed. The —2.0 per cent avail-

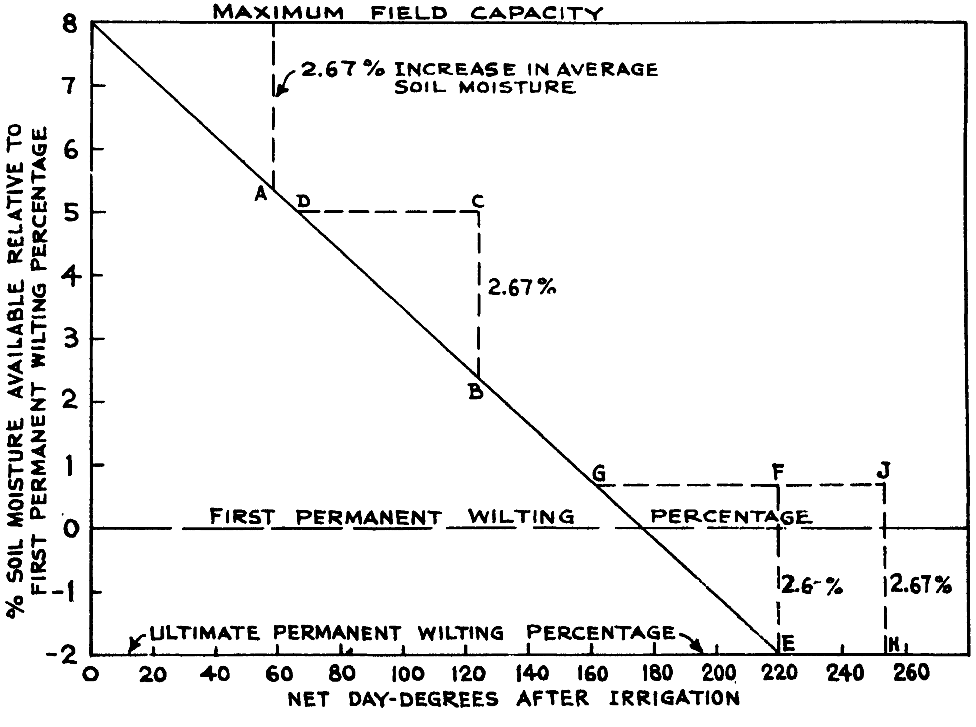


Fig. 2. Ideal soil-moisture extraction curve for H 109 cane at Waipio. (This shows method of obtaining tabular values for the effect of 1.0 inch of rain.)

able moisture, appearing on Fig. 2, is actually available to the plant. It, of course, represents the wilting range.

Fig. 2 shows the effects of 1.0 inch of rain superimposed at various points after irrigation on the ideal soil-moisture extraction curve for the Waipio soil. An inch of rain falling on this soil at any time will result in a 2.67 per cent increase in the average moisture content of the 34-inch depth of soil. This is very simply explained as follows:

Since this soil can hold 8 per cent of soil moisture between field capacity and first wilting point, and since, as shown above, this corresponds to a 3.00-inch depth of water applied on the surface, then 1 inch of water would correspond to

$$\frac{1}{3} \times 8\% = 2.67\%$$

A more detailed demonstration, requiring several pages of computations, would show the same figure.

Suppose that an inch of rain starts to fall when 58 day-degrees have been accumulated from the time of the last irrigation. The soil moisture is 2.67 per cent below *MFC* at the start of the rain, *i.e.*, at 58 day-degrees. (This is indicated by point *A* on the extraction curve.) Obviously this rain will increase the soil moisture to Field Capacity, which essentially sets the irrigation interval back to "0" on the day-degree scale. If this rain had occurred sooner, it would have had the same effect on the interval—set it back to "0," since if soil moisture is less than 2.67 per cent below *MFC*, the inch of rain is more than enough to replenish the soil and the superfluous water received is lost by deep percolation.

An inch of rain occurring at 124 day-degrees after irrigation would fall on soil with a moisture content of 2.33 per cent above the first wilting point (Point *B*). This one-inch rain would increase the moisture by 2.67 per cent, or to 5 per cent above the first wilting point (Point *C*). This is the same as retreating on the extraction curve to Point *D* which is at 66 day-degrees after irrigation. The irrigation interval is thus setback by the 1.0-inch rain from 124 to 66 day-degrees.

If the inch of rain fell on soil with a moisture content just at the ultimate wilting point (Point *E*, at 220 day-degrees after irrigation), the soil moisture would be increased from —2.0 per cent to 0.67 per cent above the first wilting point (Point *F*). This is equivalent to retreating on the extraction curve to Point *G* which is at 162 day-degrees after irrigation. The 1.0-inch rain therefore set the interval back from 220 to 162 day-degrees.

Should the inch of rain occur when the interval had reached a total of over 220 day-degrees, say 254 at Point *H*, the rain would have the same effect as in the previous paragraph; the average soil moisture would be increased to 0.67 per cent above the first wilting point (to *J*) which is equivalent to retreating on the extraction curve to *G* at 162 day-degrees after irrigation.

These examples, then, provide a correction table for one inch of rain. An inch of rain falling at any time up to 58 day-degrees after irrigation, will result in setting the interval back to "0" day-degrees. A rain of one inch occurring anywhere between 58 and 220 day-degrees, it will be noticed, set the interval back by the same amount—58 day-degrees. A one inch rain coming at or after 220 day-degrees will set the interval back to 162 day-degrees.

It should be obvious that a tenth of an inch of rain will set the interval back by one tenth the number of day-degrees as will a one-inch rain.

In setting up a table of adjustments for rains of 0.1-inch differentials the adjustments would be cumbersome and would not be spaced equally from irrigation to the ultimate wilting point if strict adherence were maintained in using 58 day-degrees per inch of rain for the value of R. Note that for 0.1 inch of rain, R would become 5.8 day-degrees. For the sake of simplicity and uniformity in tabular values we have taken $R = 60$ day-degrees, which becomes 6.0 day-degrees for each 0.1 inch of rain. Likewise, for practical purposes the values of I are in some cases shifted slightly in order that (see Figs. 3 through 11) the ideal extraction curves will intersect the ultimate wilting point at an even multiple of 6.

The discussion above describes the derivation of the adjustment table for the Waipio soil in which moisture equivalent equals 33 per cent, $P_{fwp} = 8$ per cent, and $d = 34$ inches. This table is number II in Appendix III. (Tables I, and III to IX were devised in a similar manner for the other eight soil types, but are not presented in this paper. They are available, if desired, upon request from the Agricultural department of the Experiment Station.)

OPERATION OF DAY-DEGREE IRRIGATION INTERVAL WITH ASSISTANCE OF INTERVAL ADJUSTMENT TABLES

The Interval Adjustment Table appearing in Appendix III is preceded by some pertinent "Explanations," "Rules for Obtaining Correction Values from Rain Tables," "Rules for Operation of Interval," and several illustrative sample field records. Some elaboration of these is necessary for a complete understanding of the tables, and the method of manipulating an interval when rainfall interferes. This elaboration is developed herewith, following the method of interval operation employed at Waipio, and using Table II for Waipio soil conditions. The examples which are provided give cases of adjustments made by each of the rules. The explanations accompanying the examples describe merely the manipulations of each adjustment.

As a start it is presumed that no rainfall will interfere with the interval. The management schedules an irrigation interval in day-degrees which is symbolized: C. In setting a value for C, the management recognizes that C is divided into two periods. The first period, A, is the portion of the interval from the date of irrigation to the date on which soil moisture is depleted to the ultimate wilting percentage. At Waipio, $A = 222$ day-degrees, as has been demonstrated in the discussion above.

The second period, B, is the portion of the interval between the date on which soil moisture reaches the ultimate wilting percentage and the date on which the next irrigation is to be applied. The value of B in day-degrees is selected by the management on a basis of experimental indications of that value of B which will produce an equal or greater yield of sugar with the least amount of total water for the crop. The value of B may also be selected on a basis of the age or variety of cane, or a number of other factors.

Experiments are under way at Waipio which should provide indications of relation of these factors to the desirable amount of B-period to be selected. Heretofore the selected B-period has been uniformly long, medium, or short throughout the crop length. Variety differences have not as yet been considered in selecting the *B*-period.

Experiments 102-I and 104-I at Waipio have given satisfactory indications that the appropriate length of the *B*-period for H 109 cane at Waipio is approximately 150 day-degrees, after the third or fourth month of age. Treatments in Experiment 104-I, for example, in which each interval, *C*, included 156 day-degrees of *B*-period, produced an equal amount of sugar with fewer irrigations than did treatments in which the *B*-period was 0 day-degrees. Cane tonnage was greater in the latter case.

It is not within the sphere of this paper to discuss the physiological processes or internal water economy of the cane plant which produced the results obtained in Experiment 104-I. Plant physiologists indicate: (*a*) if the plant processes are producing cellulose (growth) at a rate approaching the maximum possible, the simultaneous production of carbohydrates (sugars) will proceed at a relatively slow rate; (*b*) if some condition is imposed upon the plant which reduces the rate of cellulose production, the rate of carbohydrate accumulation will become relatively more rapid. Whether or not the physiological processes of the H 109 cane were thus affected by the irrigation treatments of Experiment 104-I is a problem for a plant physiologist to investigate, and we propose to leave it to him. Our concern is that by certain irrigation intervals several corresponding cycles of soil-moisture conditions produced the final effects on the yields. The methods we are describing should reproduce similar conditions and results whenever they are applied.

Due to immaturity of the cane and the shallow root development up to about three months of age, a *B*-period of 0 to 30 day-degrees, only, is selected by the management for starting Waipio fields. The reader is cautioned to note that the day-degrees selected for the *B*-period at Waipio are intended for use solely at Waipio with H 109 cane, and may not be applicable elsewhere or with other cane varieties. Furthermore, it should be stated here that there has never been any intent on our part to recommend that the 350 day-degrees optimum value for the irrigation interval (*C*), as indicated by the first crop of Experiment 104-I, can be used universally in the irrigation of sugar cane (6).

When a field has been scheduled for an interval of *C* day-degrees with the expectation of receiving no rainfall, and if a rain does occur, the interval is adjusted so as to take advantage of the resulting increase in soil moisture. In this adjustment, (1) the *A*-period of the interval may be prolonged; (2) the desired *B*-period of the interval may be interrupted and a certain amount of undesired *A*-period be introduced into *C*; or (3) if there is a series of rains, both situations may develop. In any case the adjustment is made in a manner which, as nearly as possible, maintains a balance between *A* and *B* that will be proportional to the original ratio of *B* to *A*.

The existence of the wilting range is also considered in making the adjustment of the interval for the rainfall received. The wilting range, of course, occurs on the day-degree scale just prior to completion of the *A* part of the interval. At Waipio the wilting range appears to occur between 178 and 222 day-degrees after an irrigation. For practical purposes 180 and 220 day-degrees are used, where necessary, in adjusting for rainfall.

The use of the interval adjustment table for controlling irrigations at Waipio has demonstrated that it is impossible to utilize merely a single record of elapsing day-degrees netted for any rainfall. This would be the ideal, but since the irrigation interval *C* is composed of two parts to be balanced one against the other, and since a record of net day-degrees after the last irrigation is actually a direct function of the condition of soil moisture, an auxiliary record must be employed under certain situations as seen in the examples provided.

The form used for irrigation control may record the net day-degrees either in a vertical column or in a horizontal row. At Waipio both have been tried, but for Waipio controls, the horizontal row with dates in columns has been found more suitable. This is the form in which the examples are set up (see insert, Appendix III). The row *N* is the net day-degree interval. Row *S* could be omitted, but to avoid any possibility of accidental carelessness it is used to record the tabular setback of the *N* record due to any effective rain. Row *X* is the auxiliary record mentioned above. Its specific use is described in the "Rules for Operation of Interval," and further explanation will be offered in due course.

In the "Rules for Obtaining Correction Values from Rain Tables," Rules 1, 2 and 3 are self-evident. Rule 4 is included because any rain occurring within 24 hours of an irrigation is essentially a part of the irrigation. Rule 5 is included for the sake of conservatism. Although as little as 0.1 inch of rain, falling on cane over 12 months of age, has been observed to increase the average soil moisture, still small rains penetrate the soil to only a shallow depth.

The "Rules for Operation of Interval" cover a number of possible situations which may exist at the time a rain occurs and a number of results of the rain dependent on its amount. These rules are devised so as to treat the possible situations with a mixture of plain common sense and theory, with emphasis on common sense and a factor of safety. The rules are intended for guidance, and there is no thought that in controlling an interval the adjustment for rainfall shall be made by strict adherence to rule of thumb, with no application of the operator's sense of good judgment in evaluating observations of field conditions.

A rain may occur during an interval under two major circumstances. The first is while the interval is still within the *A*-period, *i.e.*, the *N* record is less than 222 day-degrees, at which time soil moisture would be extracted to the ultimate wilting percentage. This case is adjusted according to Rule I. The adjustment is simply a setback of the *N* record. No attempt is ever made under this case to balance the value of the remaining *B*-period against the resulting increased gross value of the *A*-period, since a series of rains can prolong to as much as three months the time before the ultimate wilting percentage is obtained, *i.e.*, until the *N* record finally reaches *222*. In such a case the *B*-period, if balanced against the total gross *A*-period, would be disastrously long. Actually under Rule I the irrigation is applied when the *N* record reaches 222 plus the selected number of day-degrees for period *B*, *i.e.*, when record *N* reaches the scheduled value of *C*.

The second major circumstance, in which rain may occur, is that of a rain falling in the *B*-period of an interval *i.e.*, when record *N* is greater than 222 day-degrees. This means that there is no longer any readily available moisture in the soil of the root zone. In this case a given rain will always set the *N* record back to the same point, regardless of how far beyond 222 the N record may be on the date the rain starts. For example: 0.70 inch of rain, occurring when $N = 230$, sets N back to 180. If the 0.70 inch of rain occurs when $N = 300$, N will be set back to 180.

In the case of a rain or series of rains occurring during the B-period, five effects of the rain may result, depending on its magnitude. These effects are accounted for under Rule II by the five sub-rules (*a*) to (*e*). The adjustment by Rules II (*a*), II (*c*), and II (*e*) are made in the manner described because a rain small enough to set the N record back only within the wilting range between 178 to 222 day-degrees saturates the soil to only a few inches in depth. Although the average soil-moisture content rises above the ultimate wilting percentage, the bulk of the root zone is not benefited. The use of the X record thus serves as a factor of safety in insuring that these setbacks of the N record, representing small receipts of available soil moisture, will not result in an excessive interval elapsing before the lower horizons of the root zone are refilled with moisture by irrigation. A further consideration is that the amount of A-period introduced by the rain is so small that the proportional B-period to be allowed before irrigation would be negligible, hence it is better to proceed as per these three rules.

Rules II (*b*) and II (*d*) are the means by which a new proportional balance is obtained between the B- and A-periods when a rain or series of rains set the N record back of the wilting range, *i.e.*, the adjustment from the Rain Table sets record N back to less than 178. The attitude in correcting for this rain is that it is a fractional irrigation, and as such essentially stops the interval that was in progress at the time. A new interval of fractional magnitude, which must be calculated, is thus commenced. In this case the rain has saturated the root zone to a sufficient depth that the resulting fractional A-period is large enough to be balanced by a proportionally fractional B-period. The simple equation given calculates this fractional B-period and simultaneously adds it to the end of the A-period to give a revised interval, C', at which point on N record the next irrigation would be applied.

Notice that if a series of rains occurs under Rules II (*b*) or II (*d*), the setback of *least* value is used to calculate the revised interval, C'. The reason for this is that such a value for calculating C' provides a factor of safety in preventing the fractional B-period from being too large, as might be possible when a series of rains maintained soil moisture above the ultimate wilting percentage for a considerable length of time. That is, the setbacks due to this series of rains would hold the N record for some time at values less than 222, and it would be dangerous to calculate C' using for S the total day-degrees from the first rain which set N back of 178, to the date on which N reached 222 day-degrees.

SOIL TYPES DIFFERING FROM WAIPIO CONDITIONS

The rules upon which comments were offered just above are general in nature and are applicable to other soil types and conditions than are found at Waipio, *providing* that corrections for rainfall are obtained from the *proper* adjustment table. Table II which has been described at length in this paper was designed specifically for Waipio soil. It is believed that this table may be used for other localities where the moisture capacity of the soil and depth of root zone are equivalent to those at Waipio. The other eight tables are intended for use on other soil types, as indicated on the face of each table. The moisture equivalent is used as one index for classifying moisture-holding capacity of a soil, and the depth of root zone is given in inches for the other index of soil type. Since moisture equivalent varies considerably in value, the three classifications of this index appearing on the tables are given as a range of moisture equivalent in each case.

In selecting the proper adjustment table for a given field or fields, a knowledge of the moisture capacity, which can be indicated by moisture equivalent, and of the depth of root zone, which can be more or less readily determined, is necessary. Consultation with Experiment Station representatives should also assist in selection of the proper table and its use in controlling irrigation intervals. By no means should the adjustment table be selected hastily without a preliminary study of soil conditions. Some experimentation should be included for the purpose of determining for specific localities and conditions the proper length of the *B*-period to be included in scheduled intervals.

Again it is to be emphasized that, while day-degree controlled intervals are under operation with the aid of the adjustment table, personal surveillance of field conditions and general appearance of the cane should be employed in tempering the adjustment rules with plain common sense, and a small degree of conservatism.

As typical of the suggested conservatism, we would refer the reader to our Table IX which was constructed from Fig. 11. A sandy soil of shallow depth, say not over 17 inches, would require the use of this table in adjusting for rainfall. Fig. 11 indicates that the soil moisture will be extracted from this soil to the ultimate wilting point in about 50 day-degrees. The conservative attitude toward the operating of intervals and the adjusting for rainfall on this soil would be to use only Rule I, Rule II (*a*), and Rule II (*c*). No consideration should be given to possibilities of using Rules II (*b*), II (*d*), or II (*e*), thus avoiding any chance of damage to the cane. Furthermore, in this case time is so short except in winter, that any attempt to balance the *B*-period against any unexpected fractional *A*-period would result in a revised interval, *C'*, differing from the original scheduled interval, *C*, by only a few day-degrees. This would be equivalent to a fractional day or two at most. Such an attempted revision of *C* would be a waste of effort as the irrigation would probably be applied on the same date as under the original *C*.

CONCLUSION

This paper has described how the problem of rainfall evaluation has been dealt with at the Waipio Substation of the Experiment Station, H. S. P. A. A workable, practical method of rain evaluation has been offered which combines scientific theory, recognition of the character and influence of conditions observed in the field, and a reasonable degree of conservatism.

In presenting the table of adjustments for rainfall for use at Waipio, the derivation of the adjustments has been described in detail. Rules have been presented for operating a day-degree-measured irrigation interval with the aid of the adjustment table. Reasons for the nature of these rules have been explained.

In the course of deriving the adjustments, a revised concept of the term "permanent wilting percentage" is discussed. Attention is invited to the "wilting range" and later its significance in affecting the method of applying the interval adjustments is explained.

It is mentioned that eight other adjustment tables have been similarly devised and are available upon request. It is believed that these tables should provide for evaluating rainfall on soil types differing from that of Waipio.

The reader is cautioned against using universally the Waipio adjustment table and the intervals scheduled at Waipio. Individuals are urged to study their own specific soil types with the assistance of the Experiment Station, and thus select the most appropriate table for their conditions. Experimentation to determine the local optimum interval is suggested as an adjunct to successful use of that table suitable for a given soil type.

Appendix I

SOIL MOISTURE—RAINFALL—INTERVAL COMPUTATIONS

A—Explanation of Symbols Used in Equations:

MFC = Maximum field capacity of the soil (% on dry basis).

FWP = First permanent wilting percentage of the soil (on dry basis).

UWP = Ultimate permanent wilting percentage of the soil (on dry basis).

V = Volume weight of the soil. (1.1 is used in the equations below, as it is a reasonable average of the volume weight of majority of Hawaiian soils. This is a value satisfactory for general purposes as variation of volume weights lies within a small range.)

P = The range of soil moisture under consideration. (In the equations below this is expressed decimally, per equation No. 2.)

P_{fwp} = % soil moisture available to the cane plant between maximum field capacity and first permanent wilting percentage, *i.e.*, $MFC - FWP$. (This is a specific value for P.)

D = Depth of surface application of water, expressed in inches, equivalent to P.

d = Depth of soil mass involved, expressed in inches.

I = Interval in day-degrees from MFC to FWP, with no interference by rainfall.

R = Rate of soil-moisture extraction as expressed by I/D.

B—Equations Used in Soil-Moisture Computations:

No. 1 $D = P \times V \times d$ (This is the general equation expressing the manner in which the soil becomes saturated by a surface application of water.)

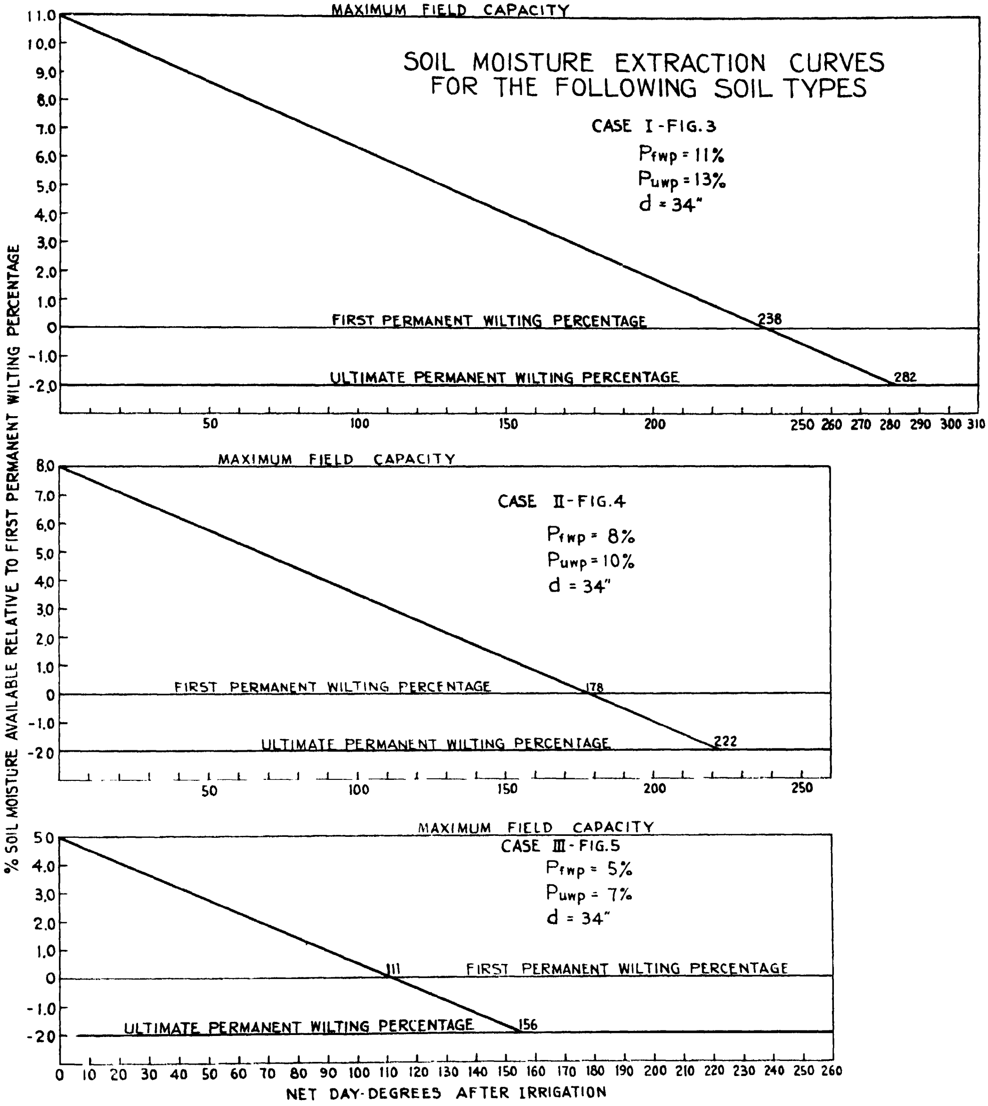
No. 2 $P_{fwp} = \frac{(MFC - FWP)}{100}$ (This equation merely converts P_{fwp} from % to a decimal value for use where P_{fwp} appears in the equations below.)

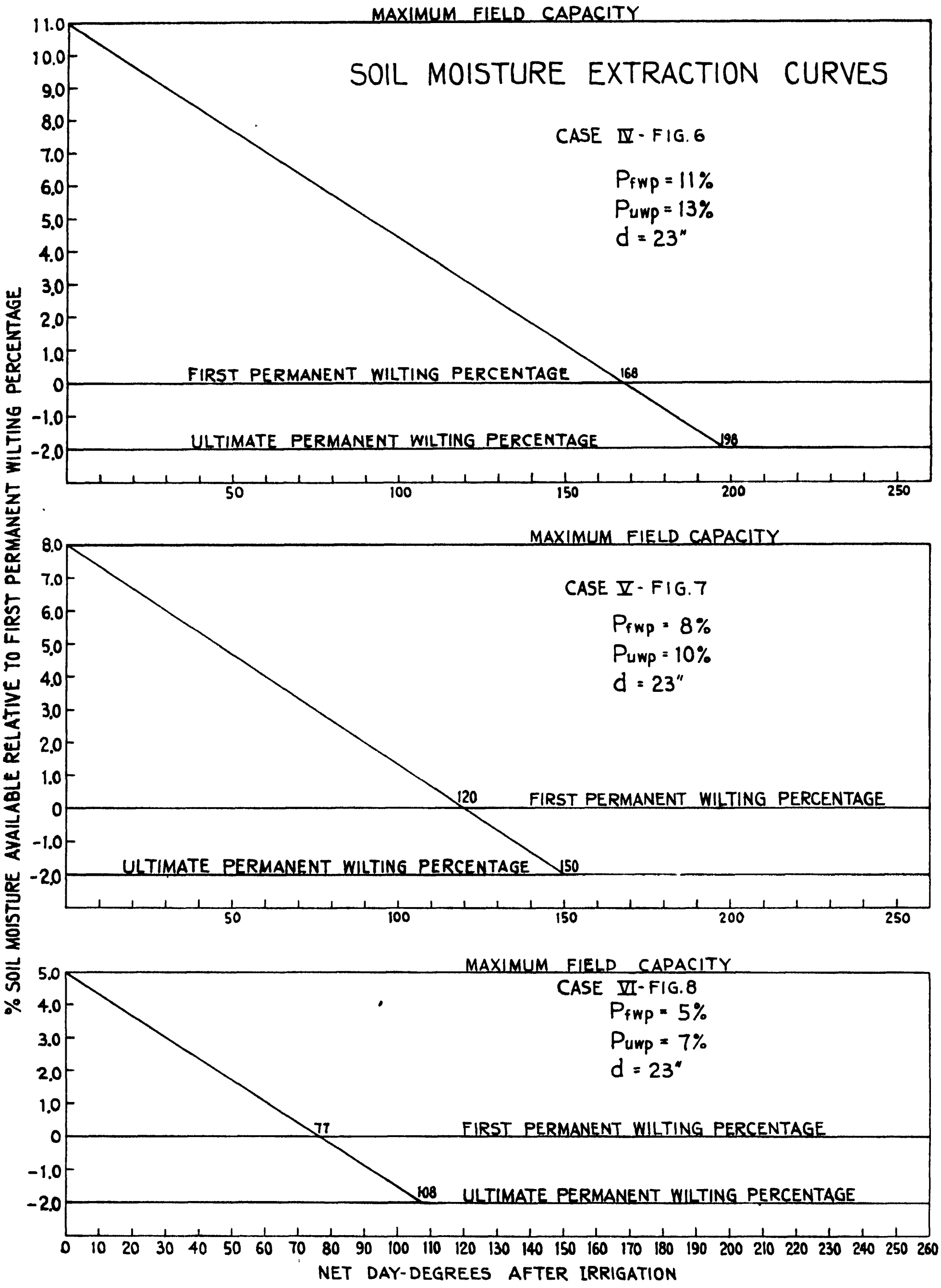
No. 3 $R = I/D = \frac{I}{P_{fwp} \times V \times D}$

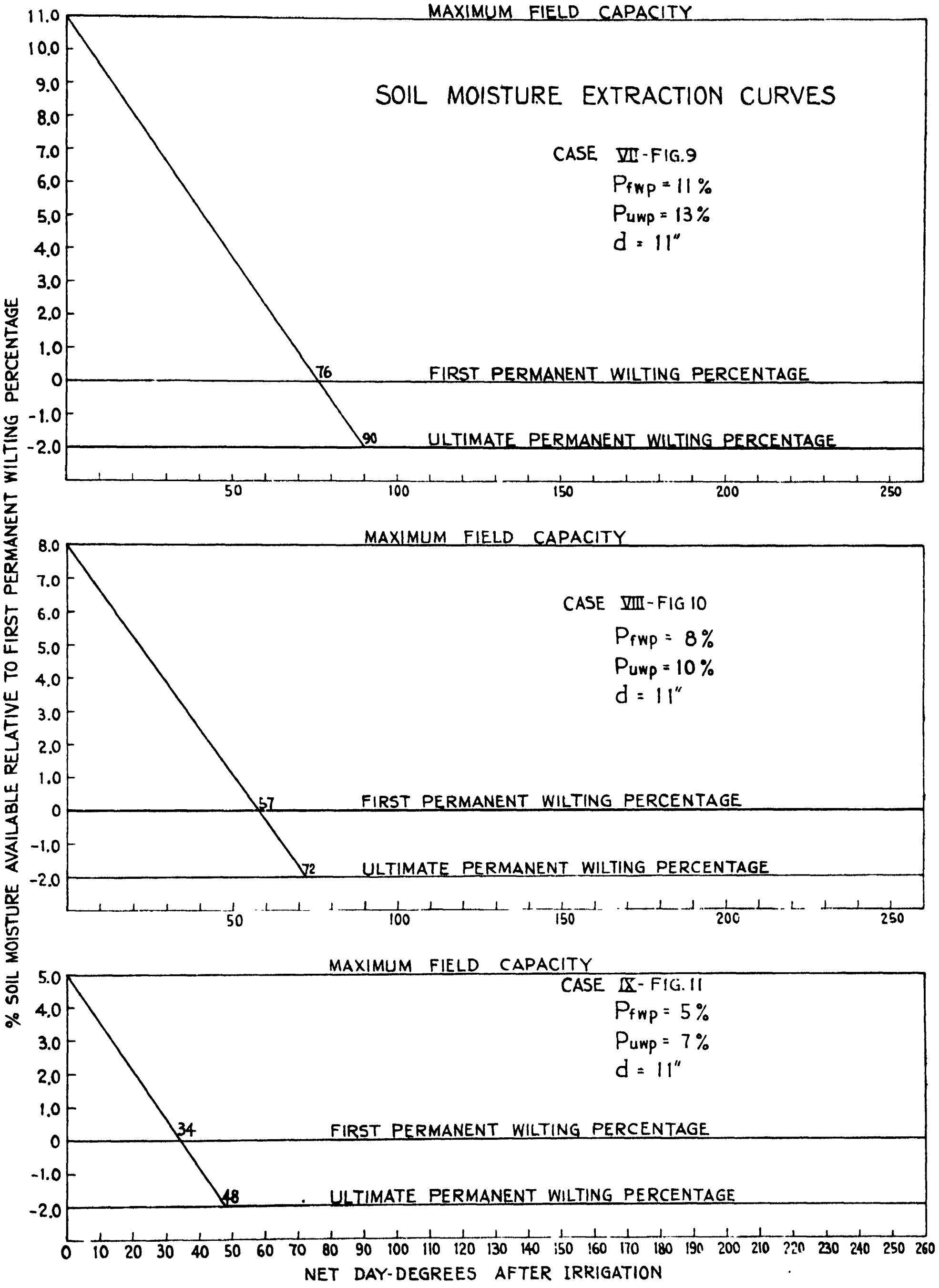
No. 4 $I = R \times D = R \times P_{fwp} \times V \times d$

Appendix II

Figs. 3–11. These graphs indicate the different day-degree periods between irrigation and the date on which available soil moisture is completely extracted. They indicate definitely that the specified irrigation interval must be scheduled with respect to the moisture-holding capacity of the soil and the depth of the effective root mass.




SOIL MOISTURE EXTRACTION CURVES
MAXIMUM FIELD CAPACITY
CASE IV - FIG. 6
P_{fwp} = 11%
P_{uwp} = 13%
d = 23"
FIRST PERMANENT WILTING PERCENTAGE
ULTIMATE PERMANENT WILTING PERCENTAGE
168
198
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
-1.0
-2.0
50
100
150
200
250
MAXIMUM FIELD CAPACITY
CASE V - FIG. 7
P_{fwp} = 8%
P_{uwp} = 10%
d = 23"
120
FIRST PERMANENT WILTING PERCENTAGE
ULTIMATE PERMANENT WILTING PERCENTAGE
150
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
-1.0
-2.0
50
100
150
200
250
MAXIMUM FIELD CAPACITY
CASE VI - FIG. 8
P_{fwp} = 5%
P_{uwp} = 7%
d = 23"
77
FIRST PERMANENT WILTING PERCENTAGE
108
ULTIMATE PERMANENT WILTING PERCENTAGE
5.0
4.0
3.0
2.0
1.0
0
-1.0
-2.0
% SOIL MOISTURE AVAILABLE RELATIVE TO FIRST PERMANENT WILTING PERCENTAGE
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260
NET DAY-DEGREES AFTER IRRIGATION


SOIL MOISTURE EXTRACTION CURVES
MAXIMUM FIELD CAPACITY
CASE VII - FIG. 9
P_{fwp} = 11 %
P_{uwp} = 13 %
d = 11"
76
90
FIRST PERMANENT WILTING PERCENTAGE
ULTIMATE PERMANENT WILTING PERCENTAGE
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
-1.0
-2.0
50
100
150
200
250
MAXIMUM FIELD CAPACITY
CASE VIII - FIG 10
P_{fwp} = 8 %
P_{uwp} = 10 %
d = 11"
57
72
FIRST PERMANENT WILTING PERCENTAGE
ULTIMATE PERMANENT WILTING PERCENTAGE
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
-1.0
-2.0
50
100
150
200
250
MAXIMUM FIELD CAPACITY
CASE IX - FIG. 11
P_{fwp} = 5 %
P_{uwp} = 7 %
d = 11"
34
48
FIRST PERMANENT WILTING PERCENTAGE
ULTIMATE PERMANENT WILTING PERCENTAGE
5.0
4.0
3.0
2.0
1.0
0
-1.0
-2.0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
% SOIL MOISTURE AVAILABLE RELATIVE TO FIRST PERMANENT WILTING PERCENTAGE
NET DAY-DEGREES AFTER IRRIGATION

Appendix III

EXPLANATIONS

C: The interval for irrigation, scheduled by management. This is divided into two periods: *A* and *B*, of which—

A: Is the portion of the interval before the ultimate wilting percentage, which is determined by moisture equivalent and depth of soil; and—

B: Is the portion of the interval that is below ultimate wilting percentage; the length of this period is selected by the management.

Wilting Range: The difference in soil moisture from the first wilting percentage to the ultimate wilting percentage.

First Wilting Percentage (*FWP*): The amount of moisture in the soil when the cane growth rate shows first retardation.

Ultimate Wilting Percentage (*UWP*): The amount of moisture remaining in the soil which the plant cannot extract.

The first and ultimate wilting percentages appear on the Interval Adjustment Tables in terms of day-degrees.

In the explanations following the examples it is presumed that no rain will interfere with *C*. In case rain interferes, the rules below provide the means for making the proper adjustments.

In the record of the progressing interval:

Row or column *N:* The net day-degree interval, as adjusted for any rainfall which occurs.

Row or column *S:* The setback adjustment at the time of rain, as obtained from the adjustment tables.

Row or column *X:* An auxiliary record to be used as described in the rules which follow:

OPERATION OF DAY-DEGREE IRRIGATION INTERVAL WITH THE AID OF INTERVAL ADJUSTMENT TABLES

See examples which follow:

Rules for Obtaining Correction Values From Rain Tables.

(1) Enter the table with the rainfall taken to the nearest 0.1 inch.

(2) Interpolation can be made vertically and horizontally between tabular values.

(3) Adjust for each day's rainfall.

(4) Ignore any rain falling within 24 hours after irrigation or after net interval = 0.

(5) In cane over 12 months of age, ignore as ineffective any rain less than 0.25 inch.

RULES FOR OPERATION OF INTERVAL

I *Rain occurring during period A.*

(1) Correct record *N* for rain, according to adjustment table.

(2) Irrigate when *N* reaches selected interval.

II *Rain occurring during period B.*

- (*a*) If the rain is of such proportion that the rain correction from the table causes a setback of the interval within the wilting range only—
  - (1) Correct record *N* and continue record.
  - (2) In record *X*, continue, without correction, the record in *N*.
  - (3) Irrigate when record *X* reaches scheduled interval.
- (*b*) If rain is of such proportion that the rain correction from the table sets the record *N* back of the wilting range into period *A*.
  - (1) Correct record *N* and continue record until end of period *A*.
  - (2) When record *N* next reaches period *B*, calculate a revised value for *C* (*C′* in the equation below):

$$C' = A + \frac{B \times (A - S)}{A}$$

In which S = the correction having the smallest value while record *N* was in the period *A*.

  - (3) Irrigate when record *N* reaches *C′*.
- (*c*) If additional rains occur after correction II (*a*), and are of such proportion that the record *N* remains in the wilting range—
  - (1) Correct record *N*.
  - (2) Continue record *X*.
  - (3) Irrigate when record *X* reaches schedule.
- (*d*) If additional rains occur after above correction II (*a*), and are of such proportion that record *N* is setback of the wilting range—
  - (1) Apply rule II (*b*).
  - (2) Discontinue record *X*.
- (*e*) If additional rains occur after above correction II (*b*), and are of such proportion that record *N* is setback into the wilting range—
  - (1) Apply rule II (*a*).
  - (2) Irrigate when record *X* reaches *C′*.

DESCRIPTION OF OPERATION OF INTERVALS IN EXAMPLES GIVEN

Four examples of field records will be described to illustrate the "Rules for Operation of Day-Degree Interval with the Aid of Interval Adjustment Tables."

The fields used are presumed to be located at Waipio Substation, and to be less than 12 months of age. The depth and characteristics of Waipio soil require the use of Adjustment Table II in correcting for rainfall. In the examples all rainfall corrections appearing in Row S were obtained from Table II.

On the form for the field record, the second column is headed "*C* Interval." In this column the scheduled day-degree interval for each field has been noted.

The third column is headed "*A*- and *B*-Periods." In this column the upper figure noted (220) is the *A*-period, the number of day-degrees which the moisture equivalent of Waipio soils indicates will be accumulated from the date of irrigation to the date on which soil moisture reaches the Ultimate Wilting Percentage. The lower figure is the *B*-period, the number of day-degrees which the management wishes to have accumulate after the soil moisture reaches the Ultimate Wilting Percentage before applying the next irrigation.

I = Irrigation applied

EXAMPLES OF INTERVAL ADJUSTMENTS FOR RAINFALL

Using Table II

OCTOBER 1941

eld o.	C interval	A-&B-per.	Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	3
			Day °	16	19	18	19	17	20	20	12	11	17	18	16	16	15	14	15	16	15	17	17	15	17	13	7	9	13	19	21	17	16	2
			Rain							.28	.17	.07					.06	.02			.04					1.26	.45				.08	.07		
A	300	220	S						91	99	105					177								I	0	0				42	57			
		80	N	16	35	53	72	89	109	111	111	116	133	151	167	183	192	206	221	237	252	269	286	301	17	13	7	16	29	48	63	74	90	11
			X																															
B	400	220	S						204	210	216					216				I					3	0				42	57			
		180	N	148	167	185	204	221	241	224	222	227	244	262	278	294	231	245	260	276	15	32	49	64	81	16	7	16	29	48	63	74	90	11
			X						241	261	273	284	301	319	335	351	366	380	395	411														
C	300	220	S		I				56	64	70					142									144	127				169	184		C′=	25
		80	N	314	333	18	37	54	74	76	76	81	98	115	132	148	157	171	186	202	217	234	251	266	283	157	134	143	156	175	190	201	217	23
			X																															
D	375	220	S						138	146	152					216									144	127				169	184		C′=	28
		155	N	63	82	100	119	136	156	158	158	163	180	198	214	230	231	245	260	276	291	308	325	340	357	157	134	143	156	175	190	201	217	23
			X									230	245	259	274	290	305	322	339	354	371													

NOVEMBER 1941

ɘld).	C interval	A-&B-per.	Date	1	2	3	4	5	6	7	8	9	10
			Day °	22	18	17	18	18	18	17	15	16	
			Rain		.27	.31							
D	375	220	S	204	204	I							
		155	N	260	222	221	18	36					
			X	260	278	295							
C	300	220	S	I									
		80	N	260									
			X										

The sum of *A* and *B* gives the value for *C*, and if no rain interferes during either period *A* or *B*, then irrigations would be applied whenever the day-degrees have accumulated to the value in Column *C*. The rules illustrated, herewith, provide for maintaining a balance, in spite of rain, between *A* and *B* proportional to the values appearing in the column headed "*A*- and *B*-Periods."

Field A:

This field had a scheduled interval of $C = 300$ Net Day-Degrees. The *A*-period was, of course, 220 day-degrees, and the management desired to have 80 day-degrees for the *B*-period of the interval.

This field was irrigated (irrigation was started at the control point in the field) on September 30. Day-degrees were accumulated in the record (or row) *N* until October 6 when $N = 109$. Rain of 0.28 inch fell on October 6-7. Table II shows that 0.28 inch of rain coming at 109 day-degrees sets the *N* record back to 91, this amount being recorded in row *S* on October 6. From October 6-7, 20 day-degrees were received (noted on October 7). This added to 91 gives 111 which is recorded in row *N* on October 7.

On October 8 the *N* record was set back from 111 to 99 in row *S* by the 0.17 inch of rain falling on October 7-8. Simultaneously, 12 day-degrees were received, so the *N* record reads 111 $(99 + 12 = 111)$ on October 8.

On October 8-9, 0.07 inch of rain set the *N* record of 111 on October 8 back to 105 in the *S* record—$105 + 11 = 116$, as appears in the *N* record on October 9.

A rainfall of 0.06 inch on October 13-14 set the *N* record of 183 on October 13 back to 177 in row *S*.

Since the four rains noted above each came when the *N* record was less than 220, the interval was in the period *A* and Rule I was applied, the next irrigation being started on October 21 when the *N* record reached 301 in accordance with the scheduled interval, *C*.

Notice that, according to Rule (1) of the "General Rules for Obtaining Correction Values from Rain Tables," the rains of October 14-15, and October 17-18 were ignored, being too small to consider as 0.10 inch for tabular correction.

From the irrigation on October 21 to the end of October, Rule I was again used four times, when rains were received while the interval was in period *A*.

Field B:

This field had a scheduled interval of $C = 400$ Net Day-Degrees, with the *A*-period being 220 day-degrees. The management desired to have 180 day-degrees for the B-period of the interval.

The field was irrigated in September, the interval reaching 241 net day-degrees on October 6, as noted in the *N* row. The 0.28 inch of rain on October 6-7 set the interval back from 241 to 204 in row *S* on October 6. The interval was in period *B* on October 6, and the rain set it back into the wilting range (204 being between 180 and 220). Therefore Rule II (*a*) was applicable, and the value of *N* on October 6 was repeated in row *X* and day-degrees were accumulated in this row without correction.

The 0.17-, 0.07-, and 0.06-inch rains of October 7-8, 8-9, and 13-14, respectively, each set the interval back within the wilting range. In these cases Rule II (*c*) was applicable. Row *N* was corrected each time to the value in row *S*, but row *X* was continued without correction. When row *X* reached 411 on October 17, a new irrigation was started. It was considered advisable to irrigate on October 17, after the *X* record had passed 400, rather than on October 16, before *X* reached 400.

From the irrigation on October 17 to the end of the month four rains occurred, each time with the interval in period *A*, and Rule I was applied.

Field C:

This field had a scheduled interval of $C = 300$ Net Day-Degrees, with period $A = 220$ Day-Degrees, and period-*B* selected by management to be 80 day-degrees.

This field received an irrigation on October 2. The rains of October 6-7, 7-8, 8-9, and 13-14, each occurred when the interval was in period *A*, and consequently Rule I was applied.

The 1.26-inch rain on October 22-23 set the interval back from 283 in row *N* to 144 in row *S* on October 22. The interval was in period *B* and was setback of the wilting range into period *A*, the value of *S*, 144, being less than both 180 and 220. Therefore, Rule II (*b*) was applied. Row *N* was corrected, as stated, on the 22nd and also on October 23, 27, and 28 for other rains. Each of these setbacks was within the period *A* but record *N* passed from period-*A* to period-*B* on October 30. Having gone through a fractional portion of an *A*-period, it was necessary to revise the value of the interval, *C*, so that the *B*-period would be proportionally smaller. This was done on October 30 as described in Rule II (*b*), a revised value for interval *C* being calculated as follows:

> For *S* in the equation of Rule II (*b*), it was found that between October 22 and 30, the smallest setback value in row *S* was 127 on October 23. The revising equation thus read:

$$C' = 220 + \frac{80 \times (220 - 127)}{220} = 220 + \frac{80 \times 93}{220} = 220 + 34 = 254$$

This value for *C'* is noted in the field record for reference as to when the next irrigation should start. (See row *S*, on October 30. It could be noted anywhere else that might be convenient. At Waipio it is noted with red pencil in same location as this example.) When the record *N* reached 260 on November 1, the next irrigation was started.

Field D:

This field had a scheduled interval of $C = 375$ Net Day-Degrees with 220 for the period *A*, and 155 selected by the management for period *B*.

This field was irrigated the latter part of September, and the N record reached 156 on October 6, on which date it was setback to 138 in row *S* by the 0.28-inch rain of October 6-7. This was a case for Rule I, as were also the effects of the rains on October 7-8 and 8-9.

The interval continued and passed into period B. Then on October 13 with *N* at 230, the rain of October 13-14 set the interval back to 216 which was within the wilting range. Rule II (*a*) was applicable in this case. The correction to *N* was made, as seen in row *S*, and the *N* record was continued in row *X* without correction. The *N* and *X* records were continued, reaching 357 and 371, respectively, on October 22. The next irrigation would have been applied as soon as possible after this date, the X record having reached approximately the scheduled interval (C). However, a heavy rain commenced on the morning of the 22nd which was sufficient to cause a setback of the N record to 144, or into period A back of the wilting range. Rule II (d) was applicable, and consequently, the N record was corrected, as seen, while the X record was discontinued. Several other rains occurred, each setting the interval back into the A-period. When the N record passed into the B-period on October 30, a revised value for C was calculated, using 127 for the value of S in the equation:

$$C'' = 220 + \frac{155 \times (220 - 127)}{220} = 220 + \frac{155 \times 93}{220} = 220 + 66 = 286$$

This value was noted on the field record, for reference as to when next to irrigate. Another rain on November 1-2 interfered by setting the N record back to 204 in row S on November 1. This setback put the interval into the wilting range, hence Rule II (e) was applicable. The N record was corrected, as stated, and a new X record was started. The field was irrigated when the X record reached 295 on November 3.

INTERVAL ADJUSTMENT TABLE II

FOR SOILS WITH FOLLOWING CHARACTERISTICS:
Depth of Effective Root Zone—34 inches
Moisture Equivalent of Soil—25-36%
Wilting Range—
FWP occurs at 178 day-degrees
CWP occurs at 222 day-degrees

Position of interval in day-degrees at start of rainfall	Inches of rainfall													
	0.1	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.5
6	0													
12	6	0												
18	12	6												
24	18	12	0											
30	24	18	6											
36	30	24	12	0										
42	36	30	18	6										
48	42	36	24	12	0									
54	48	42	30	18	6									
60	54	48	36	24	12	0								
66	60	54	42	30	18	6								
72	66	60	48	36	24	12	0							
78	72	66	54	42	30	18	6							
84	78	72	60	48	36	24	12	0						
90	84	78	66	54	42	30	18	6						
96	90	84	72	60	48	36	24	12	0					
102	96	90	78	66	54	42	30	18	6					
108	102	96	84	72	60	48	36	24	12	0				
114	108	102	90	78	66	54	42	30	18	6				
120	114	108	96	84	72	60	48	36	24	12	0			
126	120	114	102	90	78	66	54	42	30	18	6			
132	126	120	108	96	84	72	60	48	36	24	12	0		
138	132	126	114	102	90	78	66	54	42	30	18	6		
144	138	132	120	108	96	84	72	60	48	36	24	12	0	
150	144	138	126	114	102	90	78	66	54	42	30	18	6	0

Note: Data in body of this table represent position of irrigation interval as changed by rainfall. (J.A.S. 9/9/41.)

Position of interval in day-degrees at start of rainfall	Inches of rainfall													
	0.1	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.5
156	150	144	132	120	108	96	84	72	60	48	36	24	12	6
162	156	150	138	126	114	102	90	78	66	54	42	30	18	12
168	162	156	144	132	120	108	96	84	72	60	48	36	24	18
174	168	162	150	138	126	114	102	90	78	66	54	42	30	24
180	174	168	156	144	132	120	108	96	84	72	60	48	36	30
186	180	174	162	150	138	126	114	102	90	78	66	54	42	36
192	186	180	168	156	144	132	120	108	96	84	72	60	48	42
198	192	186	174	162	150	138	126	114	102	90	78	66	54	48
204	198	192	180	168	156	144	132	120	108	96	84	72	60	54
210	204	198	186	174	162	150	138	126	114	102	90	78	66	60
216	210	204	192	180	168	156	144	132	120	108	96	84	72	66
222+	216	210	198	186	174	162	150	138	126	114	102	90	78	72

Position of interval in day-degrees at start of rainfall	Inches of rainfall											
	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7+
156	0											
162	6	0										
168	12	6	0									
174	18	12	6	0								
180	24	18	12	6	0							
186	30	24	18	12	6	0						
192	36	30	24	18	12	6	0					
198	42	36	30	24	18	12	6	0				
204	48	42	36	30	24	18	12	6	0			
210	54	48	42	36	30	24	18	12	6	0		
216	60	54	48	42	36	30	24	18	12	6	0	
222+	66	60	54	48	42	36	30	24	18	12	6	0

Appendix IV

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Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
DECEMBER 1, 1941 TO MARCH 15, 1942

Date	Per pound	Per ton	Remarks
Jan. 5, 1942.............	3.74¢	$74.80	Philippines.

THE HAWAIIAN
PLANTERS' RECORD

Vol. XLVI THIRD QUARTER 1942 No. 3

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

The First Application of Nitrogen

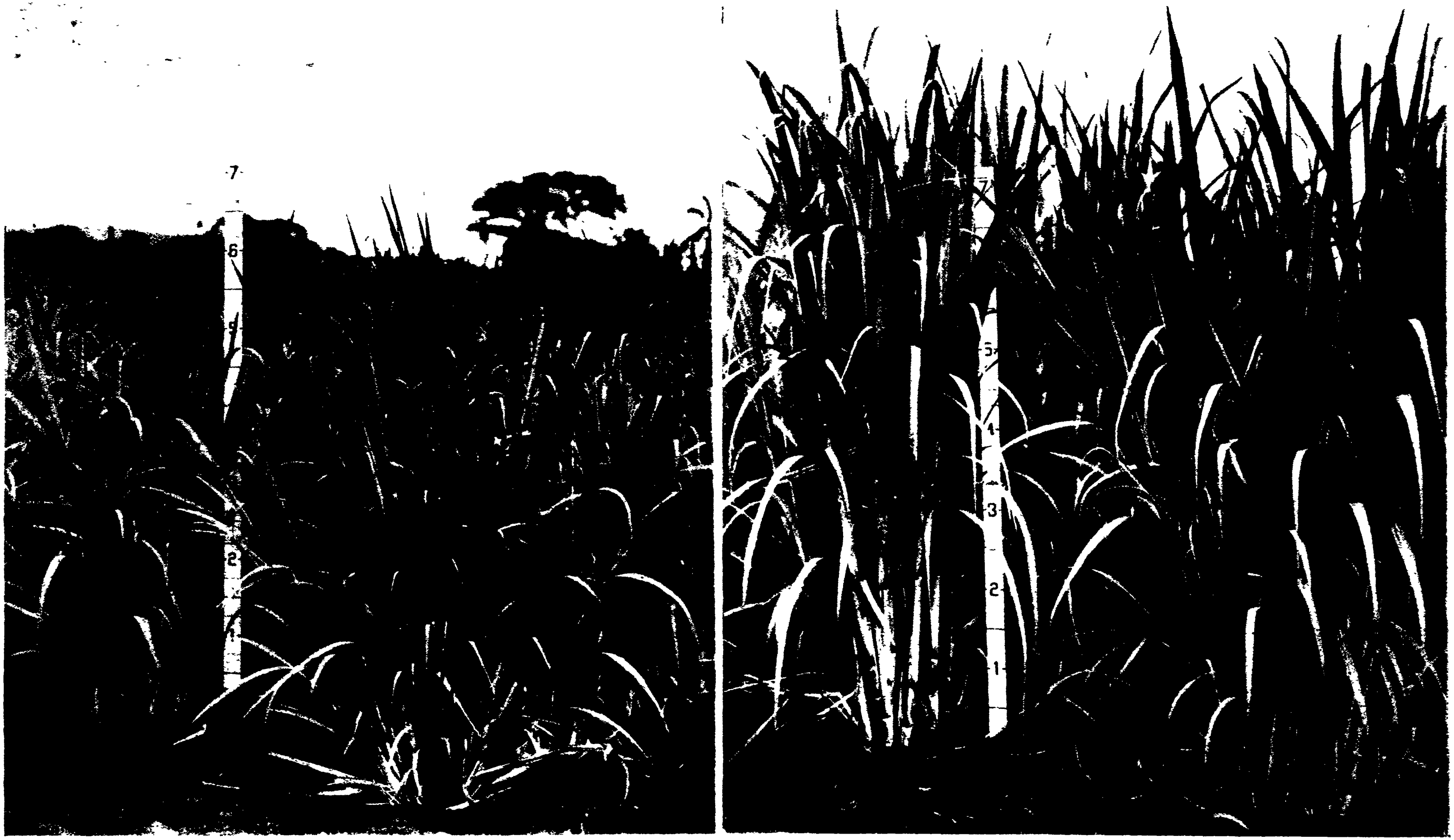
A comparison of fertilizer practices in use on the different plantations will show a considerable difference in the efficiency of applied nitrogen as measured by pounds of nitrogen supplied per ton of cane produced. Opinions have been expressed that some of the inefficiency may be associated with the use of an excessive initial application when the crop is only one or two months old, for at this stage of its growth the crop runs into its greatest competition (from weeds, soil organisms, and leaching) for the applied nitrogen fertilizer. But there has been a difference of opinion as to what amount of nitrogen constitutes an excessive application at this age. Perhaps the photographs we have taken of a crop of 32-8560 in Makiki Expt. 20 ATN, exactly four months after it was planted in May, may have a story to tell us.

The Makiki soil where this experiment is located is one which is quite low in both its total and available nitrogen status, hence it is unlikely that there has been any considerable amount of nitrogen supplied by the soil during these first four months of growth; this is quite evident when we look at the photograph of the cane which had received no nitrogen fertilizer (see page 104—left).

On the other hand, the photograph shown on the cover is one of this same crop which had received only 40 pounds of nitrogen per acre at the age of six weeks. The stalk development of this cane has been exceptionally rapid, and it is extremely doubtful that it could have been much better even if the initial nitrogen application had been a larger one.

Thus it would seem that if an excellent crop, like the one shown on page 104—right, can actually be developed in a period of four months, on a low-nitrogen soil during the best growing weather of the year, from an application of only 40 pounds of nitrogen per acre, then an initial amount which is much larger than this is probably excessive and may be inefficiently used by the crop concerned.

R. J. B.



32-8560 plant cane at four months. Left—grown without application of nitrogen fertilizer. Right—grown with only forty pounds nitrogen per acre applied at six weeks.

The Calcium Phosphate Precipitate in Limed Cane Juice

By Hugo P. Kortschak

The results of recent experimental and theoretical investigations of calcium phosphate are applied to the precipitates formed on liming cane juices. These precipitates cannot be described in terms of definite chemical compounds. The decreasing pH is caused by oxolation and by absorption of calcium. The high calcium content of clarified juice is due to several different factors.

I. *The Composition of the Precipitate:*

Although lime has been used for over a thousand years as a clarifying agent for cane juice, there is still much speculation on the nature of the precipitate formed. This precipitate has been described as hydroxyapatite (2, 11, 17), tri-calcium phosphate (2, 5, 7, 10, 18), di-calcium phosphate (10), or a solid solution of lime in secondary calcium phosphate (3).

This confusion is only natural, as the reaction of phosphoric acid with calcium phosphate has remained obscure until recently. In the past few years it has become apparent that the difficulty lies in attempts to describe the precipitate in terms of definite compounds. Any such attempt is doomed to failure, as precipitated calcium phosphate may have any composition between $CaHPO_4$ (or even slightly more acid) and $Ca(OH)_2$, depending on the conditions of precipitation (4, 6).

Practically all theoretical investigations of calcium phosphate represent an attempt to attain equilibrium. Although it is universally recognized that in cane juice clarification equilibrium is not reached, yet conclusions drawn from such experiments are applied. Fortunately, in one of the most extensive investigations of calcium phosphate solubility, that of Bassett (1), conditions were much like those which occur in the sugar mill. Bassett made up his samples using solutions of di-calcium phosphate, phosphoric acid, and milk of lime. He found it necessary to boil his solutions *at least four weeks* before equilibrium was approached. This makes it evident that the only use we can make of such measurements at equilibrium is to indicate the manner in which the precipitate will change with time.

It has been shown that freshly precipitated calcium phosphate does not possess a crystalline structure (7, 9), except for the presence of usually small amounts of $CaHPO_4$. (Even the crystals which appear to be $CaHPO_4$ may contain a much larger proportion of lime [1, 6].) Now, when a substance is amorphous, there can be only one criterion as to whether or not it is a definite chemical compound, and that is constancy of composition. Both in the case of analyses of filter cake, and in more closely controlled laboratory experiments, there is no indication of a constant ratio of lime to phosphate in the precipitates. Records at this station show that in filter cake the ratio of CaO to P_2O_5, in equivalents, can vary from 0.12 to 5.68. These extremes are, of course, due to the presence of insoluble phosphate, or undissolved lime, but the data of Bond (3), which cannot be affected in this way, show a range from 0.47 to 2.38. The ratios for the definite compounds are:

Mono-calcium phosphate, 0.33; di-calcium phosphate, 0.67; tri-calcium phosphate, 1.00; tetra-calcium phosphate, or hydroxyapatite, 1.33.

Although any composition may be described as due to solid solution of two definite compounds, the term does not seem very applicable to these precipitates, implying, as it does, the presence of at least two components which retain their identity, although intimately mixed. It is not possible to say of one calcium atom that it is part of the di-calcium phosphate, and that another belongs to the tertiary salt. If the precipitate is called a solid solution, the components are not the various definite calcium phosphates and lime, but the ions of calcium, phosphate, hydrogen, and hydroxyl, and water, not to mention a dozen other "absorbed" substances.

To summarize: the precipitated calcium phosphate obtained on liming cane juice is not a chemical compound. It has no definite composition, not even a definite structure. It is an amorphous mass, whose composition may vary between very wide limits, depending on the conditions under which it is precipitated.

II. *The Increasing Calcium Content of the Precipitate:*

The ratio of calcium to phosphate in the precipitate increases on standing, resulting in a decrease in the pH of the juice. This has long been known, both in cane juice and in water solutions, and is usually ascribed to the hydrolysis of the calcium phosphate, liberating either free phosphoric acid (5, 7), or mono-calcium phosphate (17).

This hydrolysis, however, has only been proved in cases where water was added to solid calcium phosphate, although it has often been assumed to proceed in the same manner in solutions containing lime. Lorah (15) has shown that even a phosphate as basic as $Ca_3(PO_4)_2.Ca(OH)_2$ will absorb calcium hydroxide from solutions containing as little as 0.02 gram per liter. Since clarified juice contains far more lime than this, absorption of lime is more probable than re-solution of phosphate, as the mechanism by which the calcium content of the precipitate is increased.

A slightly different explanation has been offered by Holt (12), and accepted by Behne (2) and others. This is that $CaHPO_4$ is first precipitated, followed by the much slower precipitation of more basic calcium phosphate. The latter, being much less soluble, reduces the concentration of the solution so that it is no longer saturated with respect to $CaHPO_4$, which then dissolves. This is quite certainly correct whenever $CaHPO_4$ is present in the precipitate. However, microscopic examination shows that above pH 6 there is practically no di-phosphate present (7). At the much higher pH of clarified cane juice, precipitation and subsequent solution of $CaHPO_4$ is either completely absent, or so small as to have no noticeable effect.

The sharp drop in pH which is noticed after heating limed juice may be due to a very different effect. The calcium phosphate precipitate behaves like a "polyolated" complex (14), similar to those investigated by Thomas (19). These substances contain doubly bound hydroxyl ("ol") groups, which, on heating, are converted to doubly bound oxygen ("oxo") groups, with liberation of hydrogen ion. That this actually happens is shown by the fact that heating causes the electric charge (measured, as is the pH, after again cooling) to become more negative. With either re-solution of H_3PO_4 or absorption of $Ca(OH)_2$, one would expect the charge to become more positive, whereas loss of positively charged hydrogen ion would give the observed result.

Reactions involving calcium phosphate are not, of course, the only cause of the constantly increasing acidity of clarified juice. Cook (16) has shown that prolonged boiling of sugar solutions causes a large drop in pH. This is due, at least in part, to decomposition and oxidation of the reducing sugars formed by inversion, although the possibility that the inversion process itself may be partly responsible has not been disproved.

III. *The Calcium Content of Clarified Juice:*

The high concentration of calcium remaining after precipitation in cane products, as compared with precipitation in water solution, was ascribed by Farnell (7) to the fact that "some of the lime is held in solution as the calcium salts of various natural cane juice acids." This can only be true of a portion of the original calcium in the juice, except when the titratable acidity is greater than the amount of phosphate, a most unusual case. (But this was the case in Bond's experiments with organic acids.) In practically all samples of cane juice the total acid is less than equivalent to the phosphate concentration; all the acid may be considered to be phosphoric, so that it is not necessary to neutralize other acids before precipitating calcium phosphate.

Similar large amounts of calcium in solution were noted by Behne (2) in the presence of dissolved calcium sulfate. There were 470 p.p.m. of CaO present before the addition of lime, whereas only about 120 p.p.m. were present when precipitation started in the absence of calcium sulfate.

The explanation is quite simple. The precipitation of calcium phosphate is dependent largely on pH, due to the effect on the ionization of phosphoric acid; the calcium concentration is less important. Thus the original high calcium concentration is not greatly decreased as the pH is raised by the addition of lime. In other words, when a neutral calcium salt is present in a phosphate solution, and lime is added, the calcium content of the solution increases (or decreases) roughly by the same amount as though the original calcium concentration had been zero, since the change in the composition of the precipitate is not sufficient to have any large effect. These conditions are fulfilled by cane juice, which always contains a considerable amount of calcium. Only a fraction of this original calcium can be precipitated as calcium phosphate by the addition of lime.

The fact that, as more lime is added, the excess in solution is smaller, that is, more lime is precipitated than in the absence of $CaSO_4$, is attributed by Behne to precipitation of $CaSO_4$. Inspection of his Fig. 8, however, shows that precipitation of sulfate is within the experimental error (up to the addition of three equivalents of CaO). Actually, the precipitated calcium phosphate is more basic in the presence of the large calcium concentration, and more calcium is removed from solution for this reason.

The composition of the precipitate will depend largely on the composition of the solution after addition of the lime, but before precipitation of calcium phosphate, if we may thus divide the reaction for purposes of explanation. For instance, if, after adding lime, there are 0.50 gr. CaO per liter in a water solution, and 0.70 gr.

CaO per liter in the juice, and 0.49 gr. precipitate from each, then only 0.01 gr. remains in the water solution, while 0.21 gr. remains in the juice. The difference in lime content is much more striking after precipitation than before.

It cannot be too strongly emphasized that the statements in the preceding paragraph are true in regard to the immediate precipitate only, and do not at all apply to the conditions at an equilibrium which might eventually be reached. As far as equilibrium is concerned, the lime concentration before precipitation has nothing to do with the case, only the final concentration being of importance.

The original lime content, however, is not the only cause of the high lime concentration. Above pH 7, the precipitation of magnesium hydroxide is important. For every equivalent of magnesia which precipitates, an equivalent of lime must go into solution, if the pH is to remain constant. The data of Bond show that in some cases, between pH 7.5 and 8.5, the increase in calcium in the juice is practically equivalent to the decrease in magnesium. This factor alone, according to these figures, can account for as much as 0.14 gr. CaO per liter in the clarified juice, as compared with a total CaO content of 0.2-0.4 gr. per liter.

In addition, the effective concentration of calcium ion is much smaller in juice than in a water solution. The ionic strength of a typical filtered clarified juice was calculated to be about 0.15. This corresponds to a calcium ion activity coefficient of about 0.25 (16); the calcium has only one fourth the effect that the same concentration would have in very dilute solution. Even a water solution containing precipitated calcium phosphate is not very dilute as far as activities are concerned, and the activity coefficient of the calcium might be as low as 0.8. This alone would lead one to expect the calcium concentration to be three times as large in clarified juice as in water solution.

Summary:

1. Calcium phosphate as precipitated by liming cane juice is not a definite compound.
2. After precipitation, the calcium content of the precipitate is increased by absorption of calcium hydroxide from the juice.
3. When the juice and precipitate are heated, the pH drops, due to oxolation of the precipitate.
4. Three major reasons for the high calcium content of clarified juice are: (*a*) the original calcium concentration; (*b*) replacement of precipitated magnesia by lime; and (*c*) the reduced activity of the calcium ion.

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Disease Symptoms in Lettuce and Celtuce, Caused by the Bean Leaf Hopper *Empoasca Solana* Del.

By J. P. Martin and C. E. Pemberton

The bean leaf hopper, Empoasca solana, *has been found to cause severe damage to lettuce and celtuce in Hawaii. Affected plants exhibit a yellowing followed by a chlorosis of the tips of the older leaves. In advanced stages the tissues become brown and die resulting in serious economic losses.*

The results from controlled cage experiments proved that this insect is the cause of the damage and that the degree of injury varies directly with the number of hoppers per plant.

During March 1942 a disease affecting lettuce, *Lactuca sativa*, was called to our attention by the geneticists of this Station, and as the hotter and drier season advanced the injury became more pronounced. In a number of localities the damage was severe. Pathological symptoms similar to those on lettuce were also observed in various gardens on celtuce or asparagus lettuce, *Lactuca sativa* var. *asparagina*, and endive, *Cichorium Endivia*. From our field observations it was evident that some varieties of lettuce were much more tolerant to the injury than others; the varieties New York 12, and Imperial 44 and 847 were severely affected while the green Mignonette variety was only moderately affected.

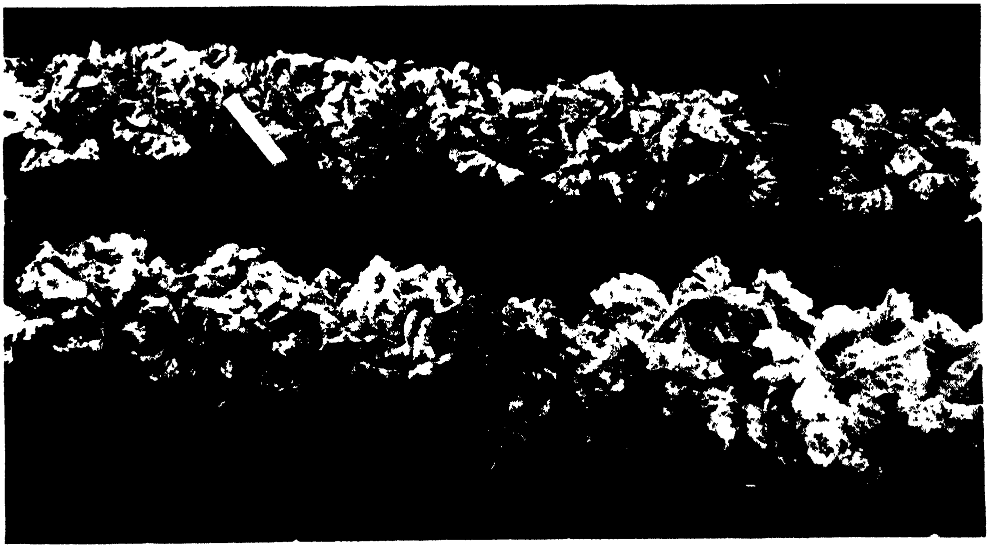

Fig. 1. Injury to field lettuce (New York 12) caused by the bean leaf hopper, ***Empoasca solana***.

DISEASE SYMPTOMS

The early symptoms are a yellowing followed by a chlorosis of the tips of the older leaves (Figs. 1, 2 and 3). When the injury is moderate the chlorosis is con-

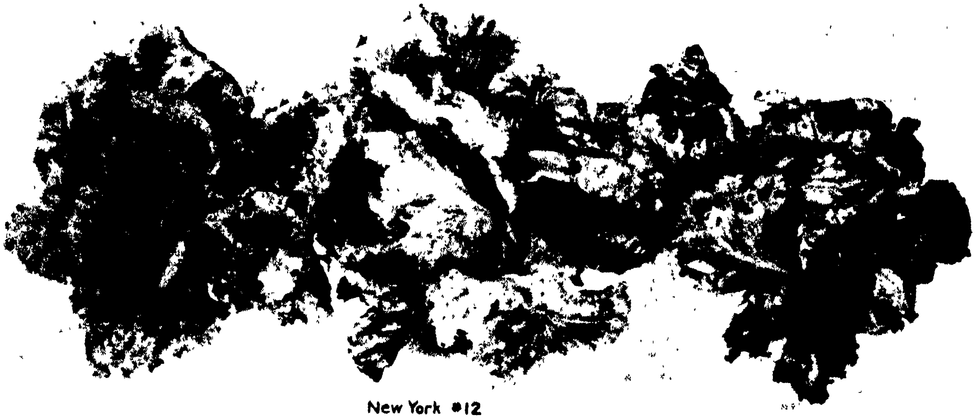

Fig. 2. Showing degrees of injury to lettuce caused by the leaf hopper, *E. solana.* Left, injury moderate; center, injury moderate to severe; right, injury severe. Note burning and dead tissue on older leaves.

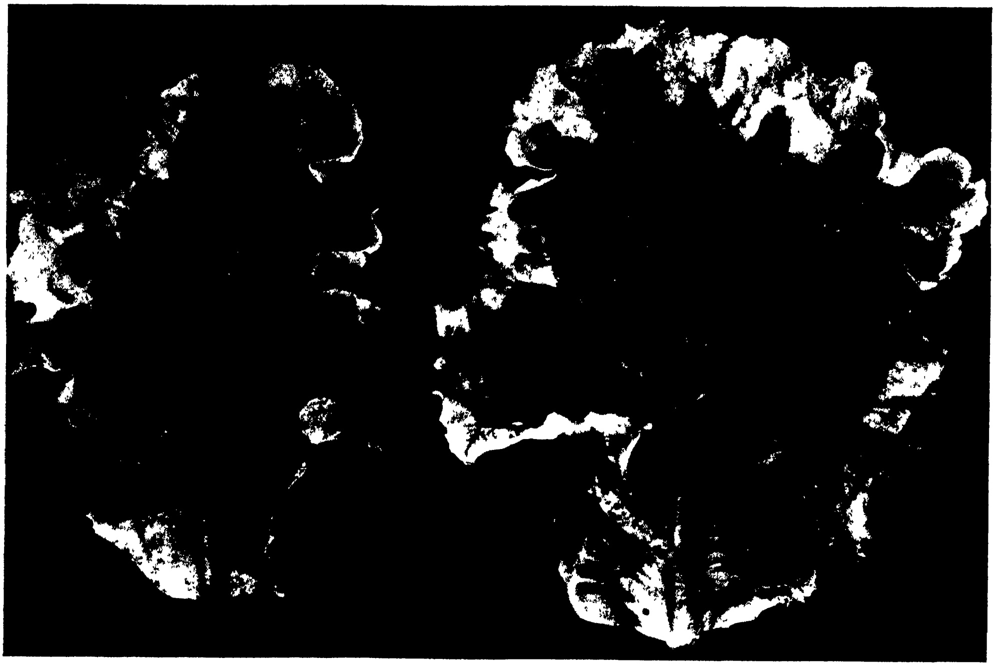

Fig. 3. Leaf hopper injury to lettuce leaves (Imperial 44). Left, injury moderate; right, injury severe. Note extent of chlorosis and dead marginal leaf tissue.

fined largely to the tips of the leaves but when the injury is severe the chlorosis includes the major portion of the leaf, as shown in Fig. 3. The affected leaf tissues, depending on the degree of injury, become brown and die, thus resembling an acute case of physiological tipburn which results from excessive transpiration. In the case of the latter the mesophyll tissues between the veins are the first to die while with this hopper-induced disease the veins are apparently affected first followed by the death of the mesophyll. These differences are used to differentiate tipburn and hopperburn in potatoes, a number of legumes and other plants.

Diseased plants are greatly retarded in growth and exhibit a marked curling of the leaves. In the advanced stages of the disease the necrotic or dead tissue of the tips and margins of the leaves is very conspicuous and many of the plants so affected cannot be marketed and frequently die.

EXPERIMENTAL STUDIES PERTAINING TO THE CAUSE OF THE DISEASE

In some respects the symptoms were similar to those described for certain nutritional deficiencies in lettuce and for this reason Experiment 1 was carried out. Since the bean leaf hopper, *Empoasca solana*, was extremely common on affected lettuce and celtuce plants, and since the nature of the injury was similar to that caused by insects of the same genus on other plants, Experiments 2, 3 and 4 were conducted.

Experiment 1: The soil, in which young lettuce and plants manifesting early symptoms of the disease were growing, was treated with an A-Z fertilizer which carries the elements essential for plant growth including the trace elements such as copper, boron, zinc, and manganese. Nitrogen, potassium, and phosphorus were applied in sufficient quantities so as to eliminate the possibility that anyone of these would be the limiting factor for normal growth. The affected plants in the treated soil failed to recover under field conditions, in fact the severity of the trouble increased with the advent of hotter and drier weather. The results from this preliminary test indicated that the cause of the disease was not directly nutritional in nature.

Experiment 2: On May 5, 1942 a large glass chimney was placed over each of 12 young celtuce plants, Fig. 4. The first 4 plants received the A-Z fertilizer (described in Experiment 1) and the next four plants remained as checks. The plants in these 8 cages were sprayed with nicotine sulphate in order to eliminate all insects. In the remaining 4 cages large numbers of the leaf hoppers were introduced. Three days later definite injury was evident on the plants in the cages heavily infested with leaf hoppers. On May 11, 1942 or 6 days after the hoppers were introduced. the older leaves of the plants were severely "burned" and the plants in general were badly stunted. On the seventh day the cages were removed and the plants were photographed, Fig. 5. The injury at this time corresponded to the advanced stages of the disease where necrosis has developed. The 8 plants without insects were normal and made an excellent growth as shown in Fig. 5.

Experiment 3: The 8 plants which were not infested with leaf hoppers in Experiment 2 were again caged immediately after the plants were photographed. Three of the plants served as checks and the remaining five were infested with 10,

Fig. 4. Caged lettuce plants used in Experiment 2. The four plants on the right were infested with large numbers of leaf hoppers while the remaining eight plants served as checks and were again used in Experiment 3.

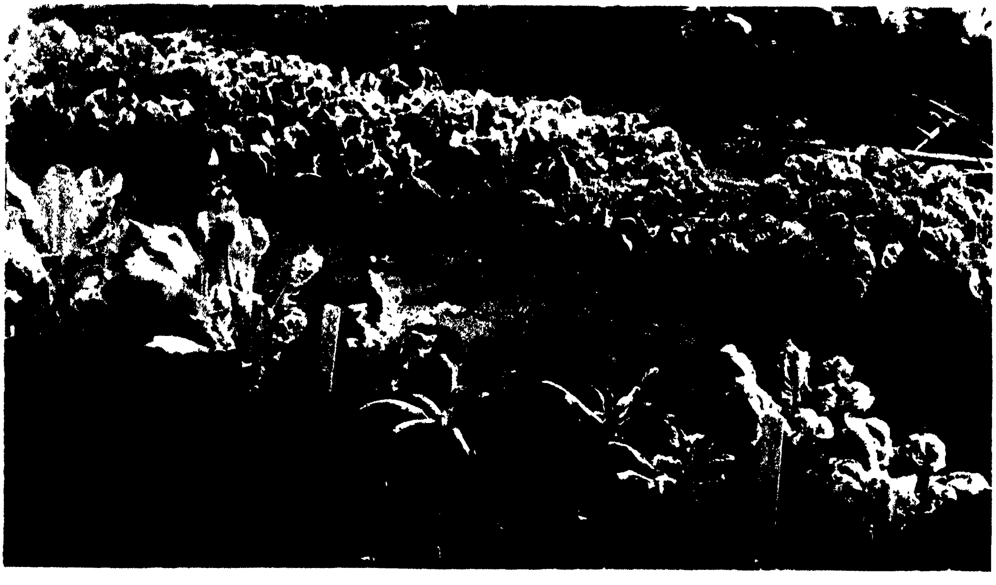

Fig. 5. The four celtuce plants, between the stakes, show severe hopper injury after the insects were allowed to feed on the plants for seven days. The check plants on the left remained normal and made an excellent growth in the absence of leaf hoppers.

19, 41, 80, and 116 leaf hoppers respectively. The object of this test was to study the degree of injury in relation to insect numbers.

At the end of 2 days definite leaf injury was noted on the plant infested with 116 hoppers and as the experiment continued the injury became more severe. Moderate-to-severe injury was observed on the plant infested with 80 hoppers on the 7th day while on the 11th day the injury was severe. The early symptoms of the disease were noted on the plant with 41 hoppers at the end of 7 days and on the 11th day the injury was moderate. The plant with 19 hoppers manifested a few chlorotic leaf tips on the 11th day. The plant with 10 hoppers developed no symptoms of disease on the 11th day when the test was photographed in the field, Fig. 6. At this time the plants were removed from the field and photographed (Fig. 7).

This test showed that the degree of injury was directly correlated with the number of hoppers per plant.

Experiment 4: One young lettuce plant of the variety Imperial 44 was transplanted on May 8, 1942 to each of twelve 12-inch concrete pots and fertilized with a fertilizer carrying nitrogen, potassium, and phosphorus. The first 5 plants were left uncovered while the remaining 7 were covered with a glass chimney.

On May fifteenth, 10, 21, 40, 80, and 138 leaf hoppers were added to five of the individual caged plants respectively—the object being to study the degree of injury by insect numbers, as in Experiment 3.

The results of this test were identical with those of Experiment 3. At the end of three days the injury on the lettuce plant with 138 hoppers was severe and only moderate on the plant with 80 insects; during the next 5 days the degree of injury on both plants became more severe. The plant with 40 hoppers showed moderate symptoms of the disease at the end of 7 days; the one with 21 hoppers exhibited only a few symptoms at the end of 10 days, while the plant with 10 hoppers manifested no visible symptoms. The insects failed to build up a population on the caged lettuce plants and at the end of two weeks most of them had died and thereafter the caged plants showed a marked recovery. The two check plants (caged) exhibited no disease symptoms and made a normal growth.

Within three weeks the check plants, which were exposed to natural insect attack, developed definite symptoms of the disease and leaf hoppers were numerous on the plants.

DISCUSSION

Within recent years a number of major plant diseases caused by insects injecting toxic substances into plants during their feeding have been studied in several countries. This type of disease differs from a virus disease in that: the phytotoxic substance is not reproductive within the plant; the affected plants frequently recover; the degree of injury varies directly with the insect population; the disease is not transmitted by plant parts (budding or grafting); and the control of the disease varies directly with the control of the insect. Some of the diseases in this group are: froghopper blight of sugar cane, mealy-bug wilt of pineapples, hopperburn of potatoes and other plants, and psyllid yellows of potatoes. Insects causing these diseases are known as toxicogenic insects, and in general the symptoms of the diseases are: a yellowing or chlorosis of the leaves, a retardation of growth,

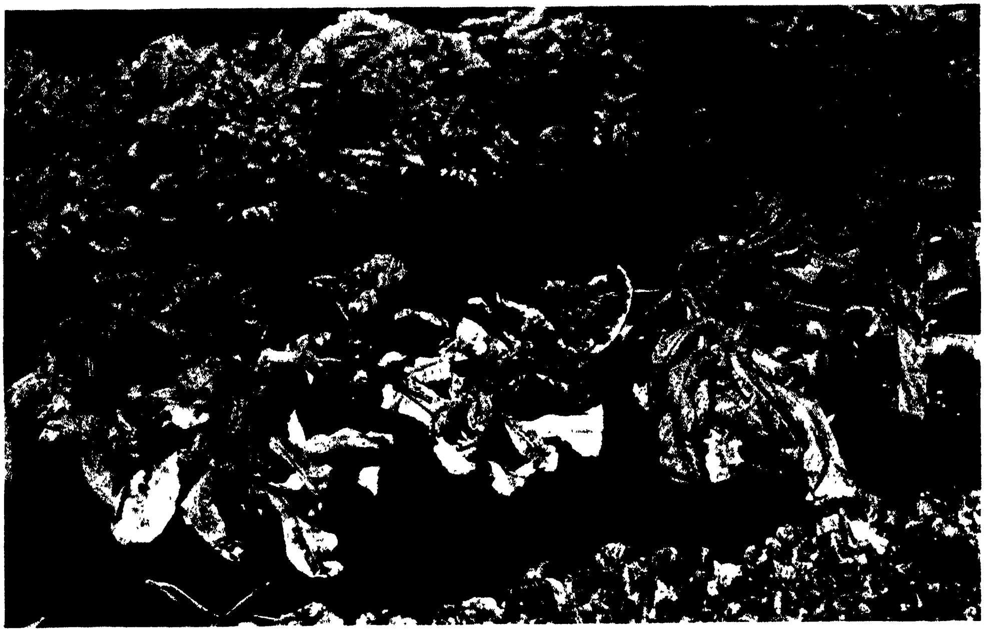

Fig. 6. The first five plants (Experiment 3) on the left show the progressive degree of injury, on the eleventh day, from 10, 19, 41, 80, and 116 leaf hoppers respectively. The check or leaf hopper-free plants on the right were normal.

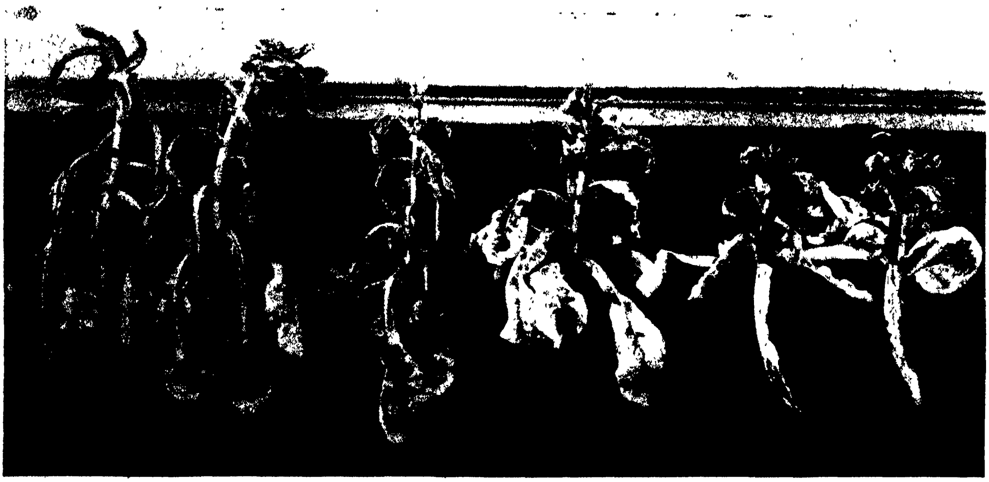

Fig. 7. The celtuce plants shown in Fig. 6 were removed from the field and again photographed in order to show more clearly that the degree of injury was directly correlated with the number of hoppers per plant. The plant on the left was a check while the others were infested with 10, 19, 41, 80, and 116 leaf hoppers respectively. The plants, upon their removal from the field had wilted slightly before being photographed.

excessive leaf curling, and a burning of the leaf tips followed by necrosis and often the death of the plants.

The potato leaf hopper, *Empoasca fabae* Harris, which is closely related to the bean leaf hopper, causes severe damage on beans, clover, alfalfa, cowpeas, soybeans and other legumes, and potatoes in the Eastern United States. The insect usually penetrates the vascular tissues with its needlelike mandibles, feeds on the phloem elements and causes a disorganization of cells somewhat removed from the feeding puncture; a clogging of the phloem has also been reported—all of which greatly interferes with the normal physiology of the plant.

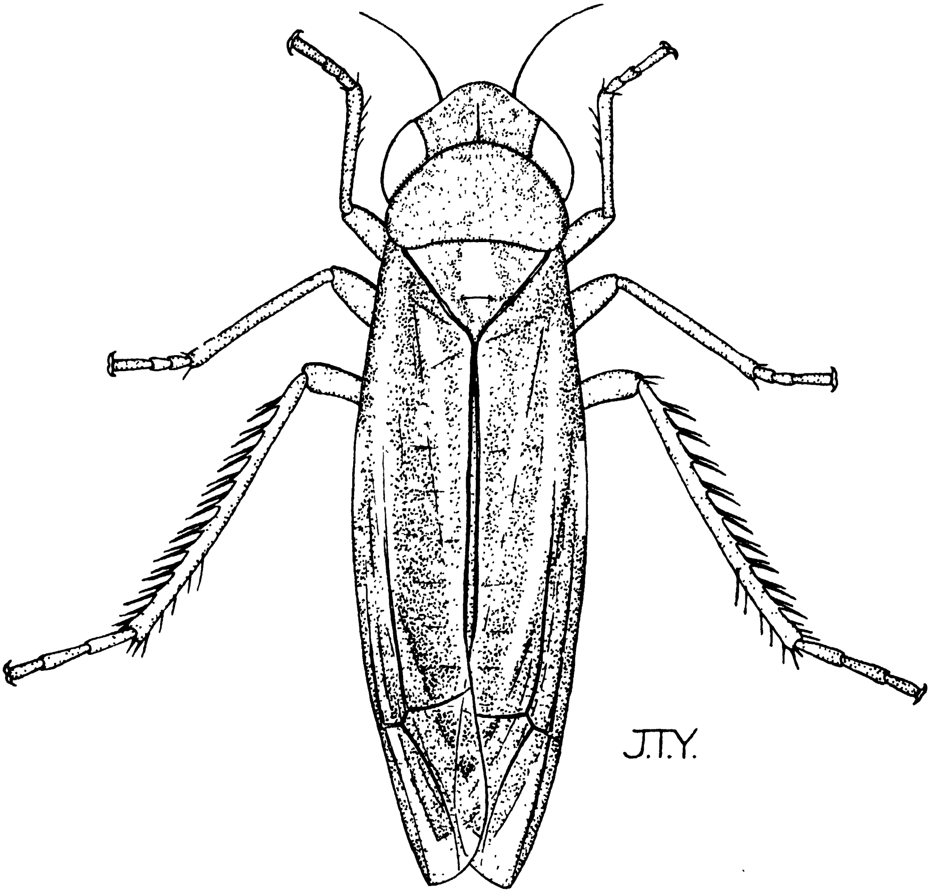

Fig. 8. The bean leaf hopper (*Empoasca solana*). Female. Color: Bright green. ×35.

The bean leaf hopper (Fig. 8) is not of Hawaiian origin. It was originally described from material collected in Louisiana. It may be considered a recent immigrant to Hawaii. The first specimen was collected on spiny amaranth on Oahu in 1918, and during ensuing years it became so common on this plant that it was referred to by entomologists in Hawaii as the amaranth Jassid. Other plants known as hosts in Hawaii are watermelon, castor bean, various solanaceous plants and garden beans of many sorts. It was not until 1937 that beans were reported to be heavily damaged by this hopper. Of all the varieties of beans grown in vegetable gardens in Hawaii today, the cowpea appears to be the preferred host.

The first reference to *Empoasca solana* as the active, causative agent of hopperburn on potatoes, watermelon and castor bean in Hawaii, is by Walter Carter.*

SUMMARY

A disease in lettuce and celtuce caused by the leaf hopper, *Empoasca solana*, is described. Symptoms of the disease have also been recorded on endive. This is apparently the first record of this disease occurring on these plants in the Territory.

From the experimental studies conducted we may conclude that: the injury results from a toxic secretion of the leaf hopper injected into the leaf during its feeding; the degree of injury varies directly with the insect population; affected plants recover when the insects are removed; and the control of the disease will be in direct proportion to the control of the leaf hopper. In the future this disease may be referred to as hopperburn.

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* Carter, Walter, 1936. Insects and Plant Diseases. Proc. Haw. Ent. Soc., IX, No. 2, pp. 159-170.

A Study of Optimum Crop Length

By R. J. Borden and F. C. Denison

Monthly rates of growth of sugar cane were differentially influenced by the month of starting the crops. Crops which were started nearer the middle of the year made a uniform monthly elongation thereafter, whereas winter-started crops showed subsequent seasonal effects which appear as both high and low peaks on their growth curves.

Growth rates for stalks of all ages were highest between July and October. Age effects, regardless of seasonal effects, showed up as an almost straight-line reduction in elongation between 8 and 25 months.

Numbers of millable stalks at harvest were not proved to be influenced by month of start or age at harvest. Average length and weight of stalks were influenced by the changing status of the stalk population.

Crusher juice analyses were influenced by the age at harvest: the per cent P_2O_5 increased with an increase in age, and both N and K_2O showed decreasing concentrations as crops became older at harvest.

Highly significant effects from both the month of start and the age at harvest were measured on yields. Interactions were not generally significant as they were apparently dominated by the age effects. Crops started in mid-season gave yields superior to those starting earlier or later, regardless of their age at harvest. The rate at which cane was produced by plant crops fell off sharply after 22 months, but the ratoons continued to make cane at a uniform rate up to 25 months. Although cane quality continued to improve with age up to 25 months, sugar yields followed the trends in cane yields, and our final answer shows that the optimum age to harvest H 109 was at 22 months for plant cane and at 25 months for ratoons, regardless of the time of starting the crop.

Begun in August 1936 and completed 5½ years later in February 1942, a study of a growing cane crop in its actual field environment* has contributed facts and verified opinions to give us a still better understanding of the sugar cane crop. As originally outlined, our objective was a study designed to furnish specific information concerning: (*a*) the rate of growth of sugar cane at its various stages of development in different months of the year, and (*b*) the optimum age to harvest H 109 cane started at different times.

Plan:

The field area selected consisted of 24 sections of 18 lines each in Waipio Field 37; each of these sections was divided into 8 two-line plots, plus an extra guard line at top and bottom. One section was planted each month for 24 consecutive months. Superphosphate carrying 100 pounds P_2O_5 per acre was applied with

Waipio Expt. 101AH.

the seed and efforts were made to insure a full stand in each line. No phosphate fertilizer was given to the ratoon crops. Adequate irrigation was given in each section throughout the crop; no attempt was made to "dry-off" before each harvest. Fertilizer was applied on each section according to a definite and similar schedule, *i.e.,* (1) 30 pounds N at 1 month, (2) 50 pounds N at 3 months; (3) 50 pounds N at 5 months; (4) 50 pounds N at 7 months, and (5) 80 pounds N and 74 pounds K_2O at 10 months.

In each section of the plant crop, starting at the time when the basal dry-leaf internodes of canes were clearly visible, 50 adjacent stalks in the 16th row were tagged for subsequent monthly growth measurements. For the ratoon crop, 40 stalks—5 in each of the 8 groups which were started in the same month—were measured for their average monthly elongation. Replacements for many stalks which tasseled or died were necessary to keep the total number of living stalks being measured monthly at not less than 30 in each group.

During harvesting of the plant cane at ages from 18 to 25 months, measurements, weights, and other harvest data were secured from all cane cut from the inside 40 feet of rows Nos. 3, 5, 7, 9, 11, 13, 15 and 17 respectively. As the plots of plant cane were harvested, they were immediately ratooned so that subsequently we were also able to secure similar measurements and yield data in the ratoon crops from rows Nos. 2, 4, 6, 8, 10, 12, 14 and 16 respectively. Treatment of ratoons was as similar as possible to that of the plant crops. Minor deviations from these specific plans of procedure were sometimes necessary, but a careful study of the effects from these deviations ultimately indicated that they had contributed only an insignificant amount to the total variations measured.

Presentation of results:

In earlier progress reports on this study, we calculated and presented "running averages" for the various measurements made, in order to smooth out the extreme variability of the field data which were secured. Since the data have been collected by many individuals* and from very small areas of canes which had received normal field practice, it is only natural that some wide variability was encountered. In this final report, since the tabulated figures are so voluminous, we have presented most of the data graphically, without "smoothing," so that the reader may if he wishes make further use of the specific values shown on the graphs. In their interpretation, however, the trends shown by the graphs should receive more consideration than the actual values themselves, and abrupt deviations from these trends may be considered as most likely due to the experimental errors involved.

Monthly rates of growth (Fig. 1:—12 graphs):

In these graphs we have recorded the average monthly increase in stalk elongation made by comparable groups of selected canes, 6 to 8 months old and up to 25 months of age, in crops started in each month of two consecutive years (the actual month in which the respective ages were attained is also indicated). Both plant and ratoon crop growth records are plotted.

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* All assistant-agriculturists-in-training who have been at the Waipio Substation since August 1936 have assisted in the planting, fertilizing, measuring, sampling, and harvesting operations involved in this investigation. Their painstaking and valuable assistance is hereby acknowledged.

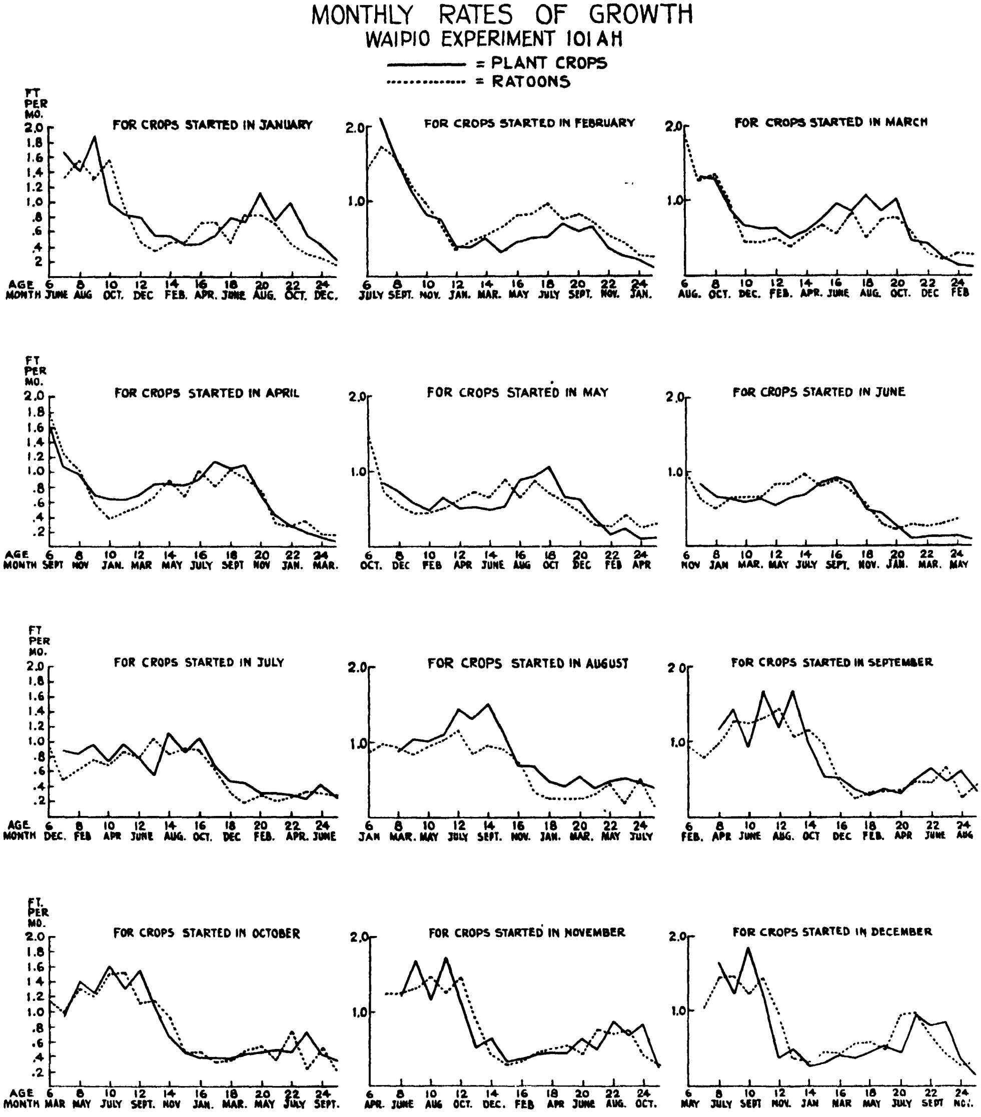

Fig. 1

Striking similarity of the plant and ratoon crop elongations is apparent. This would indicate that the growth response of healthy, non-tasseled stalks from plant and from ratoon crops has not been significantly different.

Rates of elongation for crops started in different seasons show quite different patterns. For instance: (*a*) The growth rate for crops started in January was apparently at its high point in late fall when the cane was 8 to 10 months old; thereafter it was drastically checked by winter conditions. It recovered and attained a second but greatly reduced peak during its second summer at about 20 months of age. (*b*) Cane started in March was not growing as fast at 8 months in October as the 8-month old cane from the January starts; the first winter growth rates however were not materially different, and the second-season growth peak occurred at about the same time of year but when this crop was about 18 months old. (*c*) For May-started crops, the initial first-season growth peak noted in earlier started crops is missing, and the rate of growth, though much reduced, is seen to be without any great fluctuation for nearly 18 months; the second-season growth peak, if we may conjecture it, has apparently moved farther to the left and was effective before the crop was 18 months old. (*d*) The July-started crops had quite similar growth rates to those started in May; again the peak of second-season growth has moved farther to the left and indicates an effect on still younger cane; furthermore the

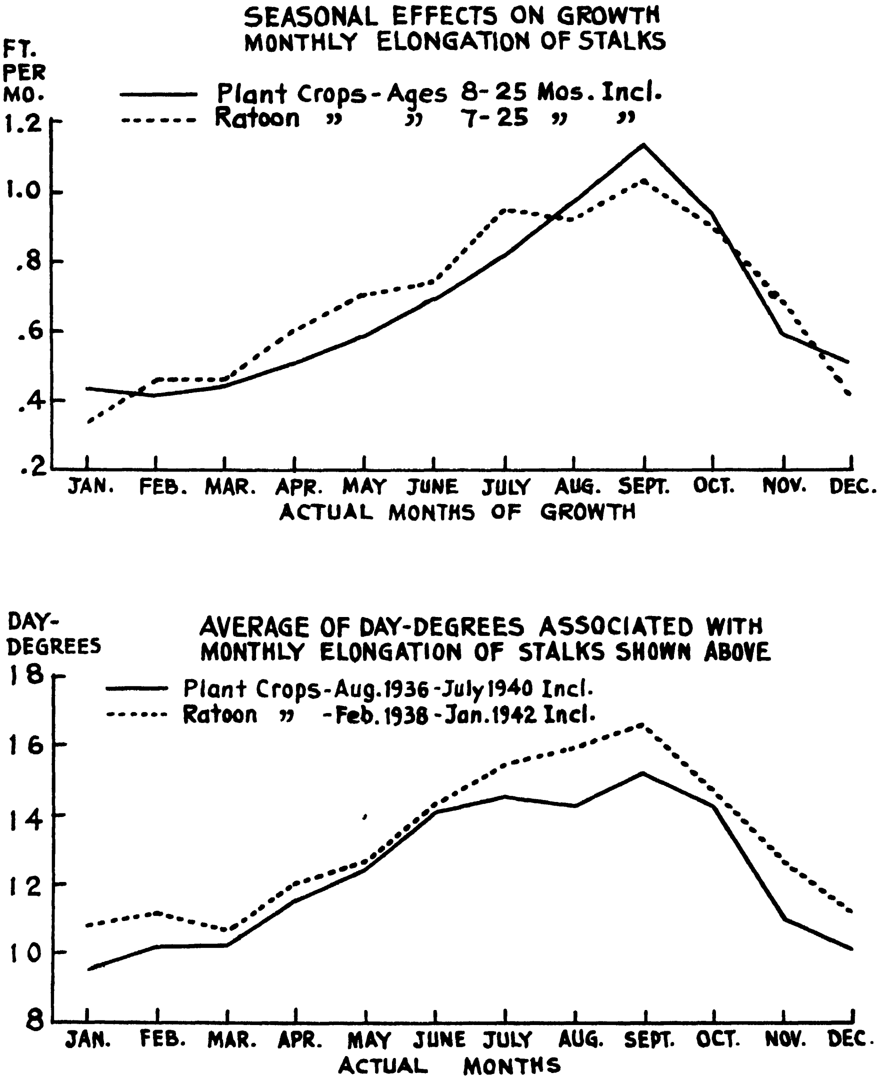

Fig. 2

growth rate for cane older than 16–17 months stays at a very low level. (*e*) Crops started in September reached their highest growth rate about 12 months later; winter weather then cut this rate to about one third and, after the canes were 15 months old, they averaged less than one-half foot of new growth per month. (*f*) The curve for crops started in November approaches that for January-started crops, showing the same excellent early growth rate checked by the winter, but the second-season peak of growth coming slightly later, at 22 to 23 months.

These representative growth patterns which we have measured are different chiefly in the range between their high and their low points. Crops started in mid-season show a more uniform growth rate throughout their critical growth periods, whereas both the early- and late-started crops show more definite seasonal effects, with growth rates at some seasons more than three times those at others. Whether these facts are contributory causes to cane quality is not known for certain, but it is an interesting coincidence that the yield-per-cent cane from these crops which were started in mid-season was generally superior (See Fig. 11).

Seasonal effects on growth (Fig. 2):

To better visualize the effects on the average monthly stalk elongation in a crop of cane carrying a mixed millable-stalk population of different ages, we have prepared Fig. 2. This is based on measurements from 30 to 50 stalks of plant cane or 20 to 40 ratoon stalks, of each age from 7 or 8 to 25 months inclusive, taken in each month of the year during two consecutive years; thus each point on this graph represents a measurement of not less than 1080 stalks from plant crops and 720 stalks from ratoons.

The high growth value of the months of July to October verifies our previously held opinion that the optimum H 109 cane growth is during these months. Similarly we have been aware of the low rate of growth which is usually made be-

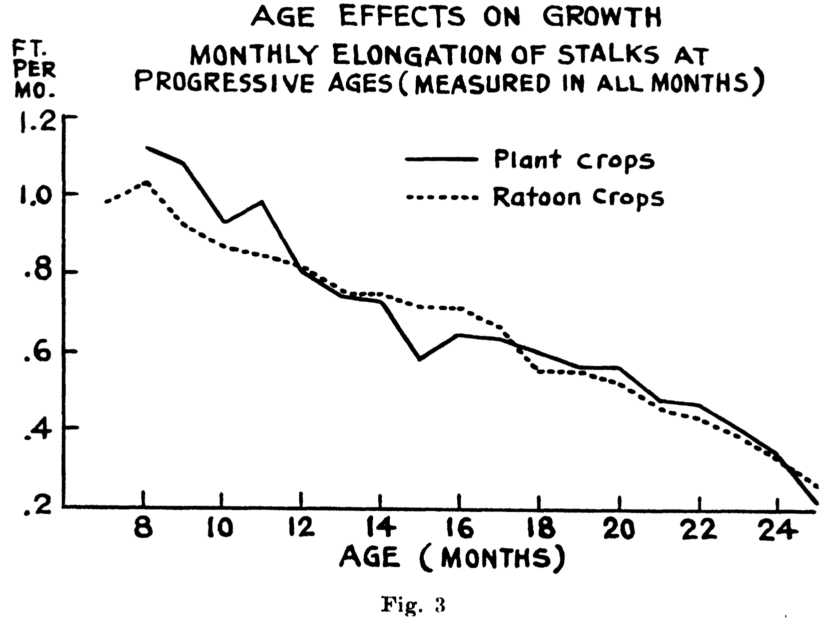

Fig. 3

tween December and March. Quantitatively, it is now convincingly seen that the value of the July-October growth rates is more than twice that of the December-March rates.

A graphical presentation of the average day-degrees associated with these seasonal growth measurements is seen to have a fairly good relationship, and again reflects the positive effects of maximum temperatures on cane growth.

Age effects on growth (Fig. 3):

Growth measurements on both plant and ratoon crops were similarly affected by the age of stalks, and Fig. 3 shows an almost straight-line reduction in monthly stalk elongation for canes between 8 and 25 months of age. Data for this graph came from stalk measurements made in every month for 24 consecutive months on cane at all ages indicated; hence each point is an average of not less than 700 measurements on plant cane or 480 on ratoons.

Combined age and seasonal effects (Fig. 4):

A statistical study of the relationship between age effect and seasonal effect upon these growth measurements shows that both of these factors probably acted independently of each other, *i.e.*, their interaction was dominated by their separate influences. The magnitude of their effect was, however, somewhat different, and this is shown by Fig. 4.* For instance, plant canes of all ages grew twice as fast in July-August as in January-February but the actual July-August elongation for canes 20–22 months old was only half that of canes 8–10 months of age. Also, although the maximum growth rate for cane of all ages came in September-October, this maximum for cane 20–22 months old was seldom as great as the minimum growth which was made by 8–10-month old cane during its winter season.

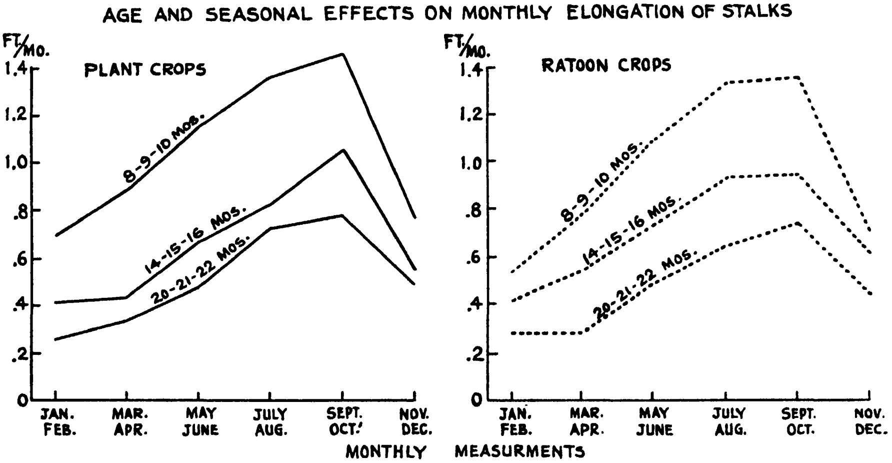

Fig. 4

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* Graphs for cane of ages 11–12–13, 17–18–19, and 23–24–25 months have been omitted for clarity; they fall intermediate between those for ages shown.

Stalk census at each harvest:

A census of the entire stalk population within a 40-foot section of cane row was made at each harvest. From Fig. 5 it would appear that the number of millable stalks per foot of row found in the plant crops was somewhat greater and also quite different from that of the ratoons. Seasonal effects on the plant cane crops indicated more millable stalks at harvest from cane planted in the August-to-February period than from March to July. However, this observation was not supported by the ratoon crops since they appear to have matured more stalks from the crops started in mid-summer.

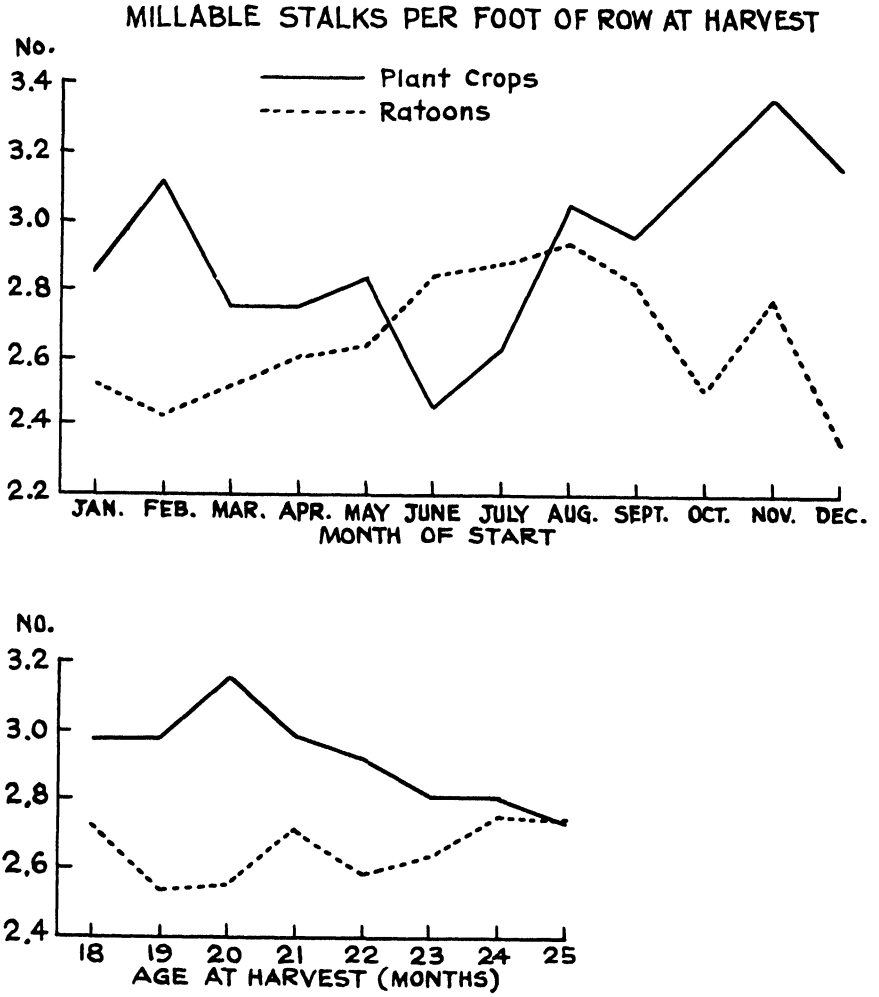

Fig. 5

The effect of age at harvest on the number of millable canes was also different for the plant and ratoon crops. In the plant crops there were definitely less millable canes harvested progressively after 20 months, whereas in the ratoons the trend appears to have been in the other direction. Thus it appears doubtful that we can generalize with respect to the effect of age at harvest or of the month of starting on the number of millable stalks to be found at harvest.

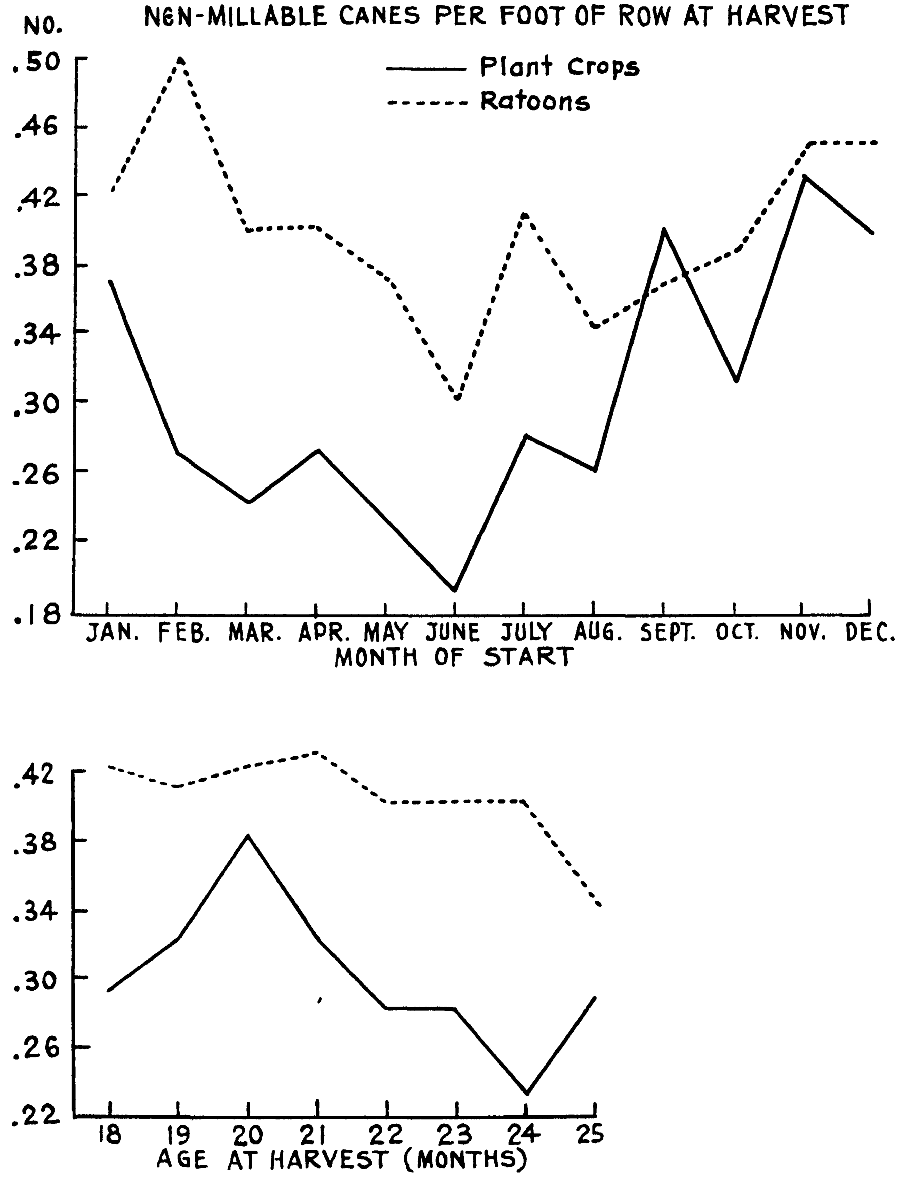

Fig. 6

In Fig. 6, it is clearly shown that the ratoon crops had many more non-millable stalks at harvest than the plant crops. Furthermore, we note more non-millable canes from crops started at the beginning and at the end of the year than from those which were started in mid-season. Perhaps also there is a reduction in the number of non-millable stalks which is an effect of an increase in age at harvest.

The number of dead stalks found in the ratoons was also greater than found in the plant crops; it increased quite similarly with advanced age. The effect of month of start on dead canes at harvest was entirely dissimilar for the two crops studied; apparently the age at harvest was the more dominant factor (see Fig. 7).

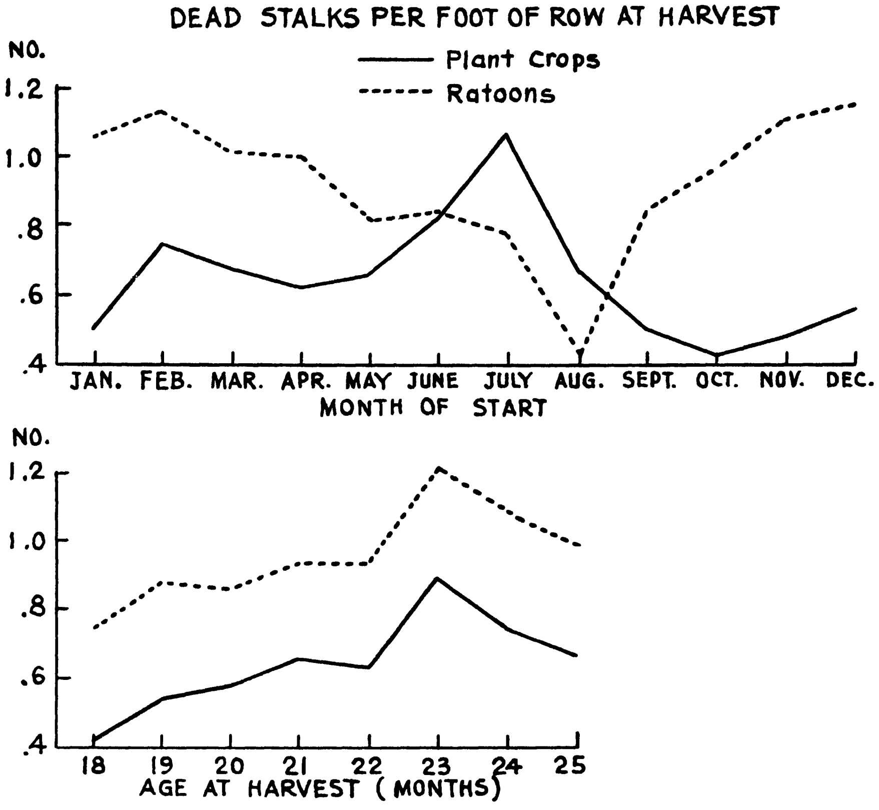

Fig. 7

Length and weight of millable stalks at harvest:

From Fig. 8, it is apparent that the millable stalks from the plant crops were slightly longer than those from the ratoons and, in general, longer stalks were harvested from crops which were started in the better growing months or mid-season.

The actual average length of all stalks milled at harvest increased with age, but was undoubtedly influenced by the changing status in the stalk population.

Millable stalks from the plant crop were heavier per foot of stalk than from the ratoons (see Fig. 9). Those from crops started earlier in the year were somewhat heavier than those which were started late. The effect of age at harvest was not entirely consistent on the two crops compared, although there seems to have been a falling-off in pounds-per-foot of stalk at the more advanced ages; this also is most likely an effect of the changing stalk population.

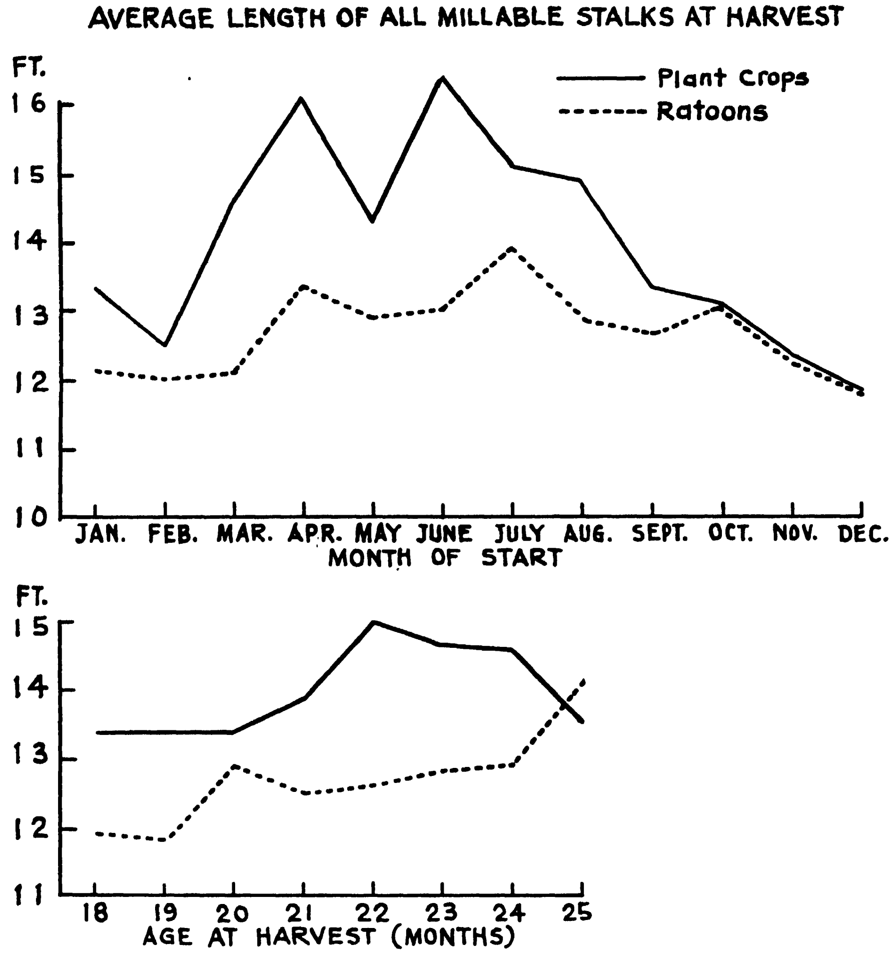

Fig. 8

Crusher juice analyses:

In addition to sugar and glucose analyses, crusher juices were analyzed for their percentages of nitrogen, phosphoric acid, and potash. These data are presented in Fig. 10.

It is quite apparent that these juice analyses have varied to a considerable extent, this in spite of the fact that the N, P, K, fertilization has been similar (except for phosphate) and the soil of the entire area was not too heterogeneous.

Phosphate was supplied only for the plant crop; thus it is interesting to note that in general the ratoon crops had slightly higher concentrations of phosphates at harvest. Plant crops which were started late in the year had higher percentages of phosphate in their crusher juices than crops started earlier; juices from ratoon crops showed just the opposite effect from their time of start. In both crops, however, increasing concentrations of phosphate were found as the crops became older at harvest.

The percentages of potash in juice were higher in the plant crops. The influence from month of starting the crop was exceedingly variable, and followed quite different patterns in the plant and ratoon crops. The effect of increased age at harvest was to reduce the per cent K_2O, and this feature was common to both crops.

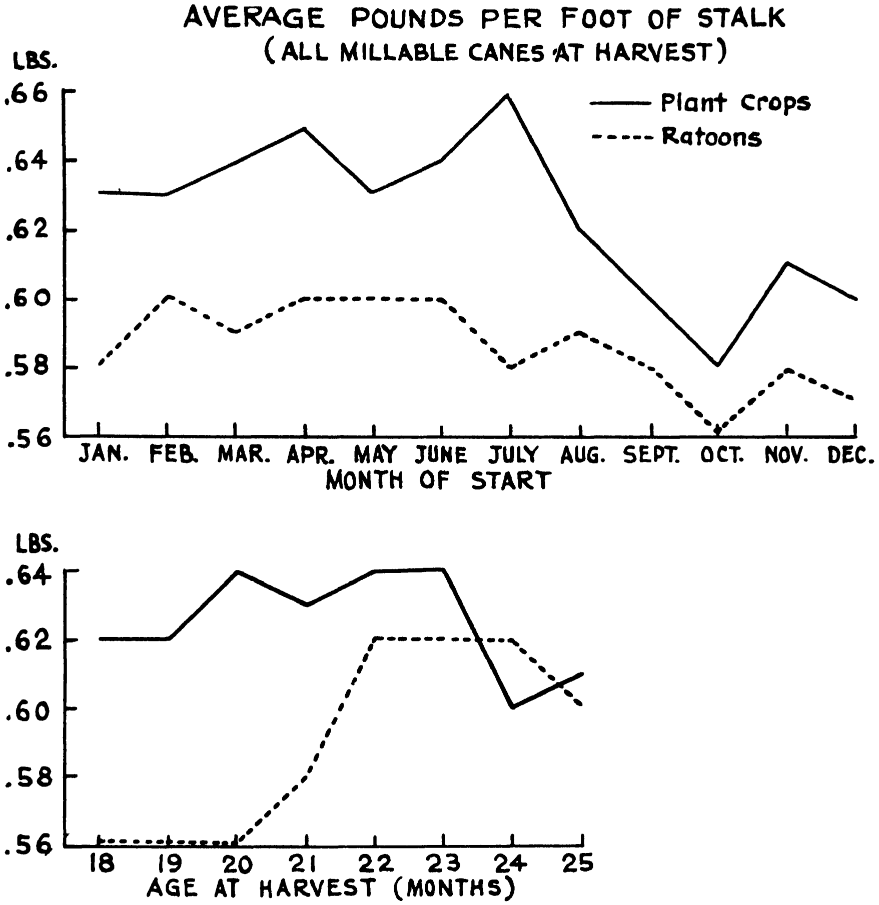

Fig. 9

Crusher juice concentrations of nitrogen were perhaps not greatly influenced by the month of start for either plant or ratoon crops, although there may be an indication of slightly higher nitrogen percentages from crops started in the better growing months. Age at harvest affects the per cent N in the same way as it does per cent K_2O, *i.e.*, a definite decrease in N with an increase in age. Thus it is seen that whereas the per cent P_2O_5 in the juice *increases*, the concentration of both N and K_2O *decreases* with advancing age at harvest.

Yields:

Although the data discussed above are of interest mainly in helping us to appreciate how the cane crop develops and responds to different seasonal and age effects, the actual "pay-off" for the planter comes only after all of these growth factors have been integrated and show their combined effects in the yield data.

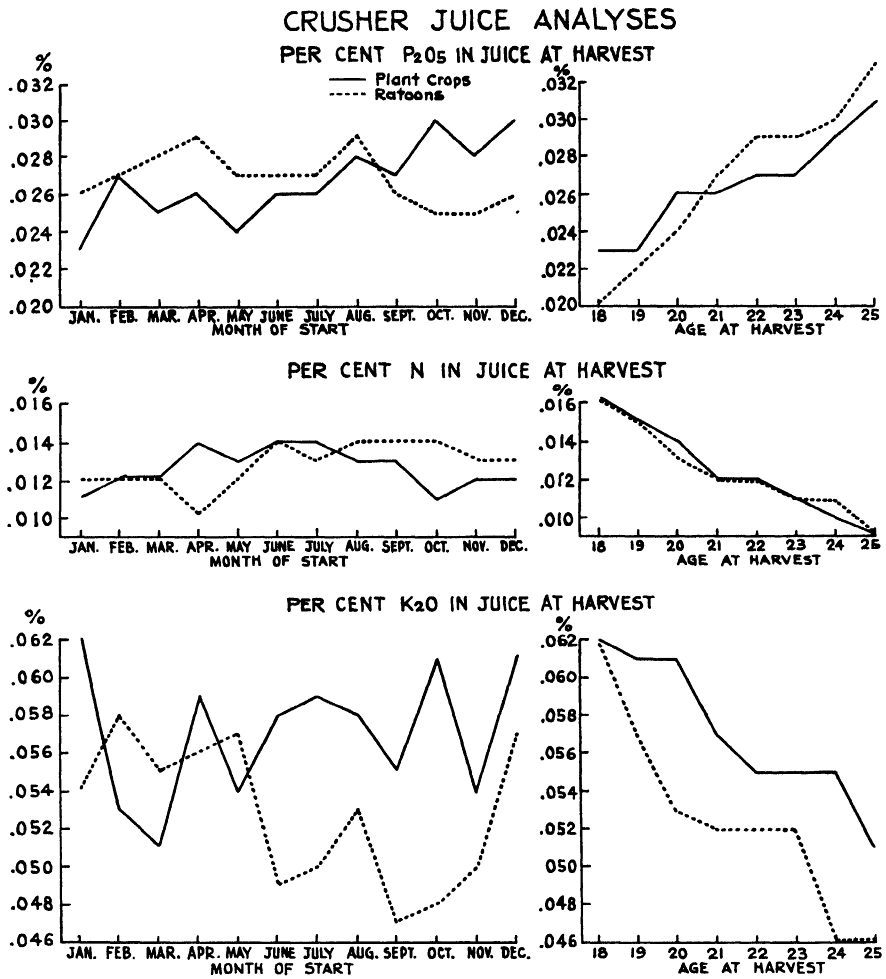

Fig. 10

TABLE I
SUMMARY OF YIELDS FROM PLANT AND RATOON CROPS

(1) Effects of Month of Start

Total plots	Month of start	TCA Plant crops	TCA Ratoon crops	Y%C Plant crops	Y%C Ratoon crops	TSA Plant crops	TSA Ratoon crops
16	Jan.	101	76	11.4	12.5	11.5	9.6
16	Feb.	105	75	11.1	11.8	11.4	8.6
16	Mar.	109	78	11.4	12.0	12.3	9.6
16	Apr.	121	88	11.1	12.6	13.5	11.2
16	May	110	89	12.2	12.4	13.1	11.2
16	June	113	97	12.5	13.1	14.1	12.9
16	July	112	99	12.5	13.4	13.7	13.3
16	Aug.	124	98	12.2	13.3	14.9	13.2
16	Sept.	103	91	12.6	13.3	13.0	12.1
16	Oct.	104	79	13.1	12.8	13.6	10.1
16	Nov.	108	85	11.9	12.5	12.7	10.6
16	Dec.	95	69	11.6	12.2	11.0	8.3
Minimum difference required for significance		15	12	.6	.5	1.9	1.6

(2) Effects of Age at Harvest

Total plots	Age at harvest	TCA		Y%C		TSA	
		Plant crops	Ratoon crops	Plant crops	Ratoon crops	Plant crops	Ratoon crops
24	18 Mos.	106	79	10.8	11.6	11.4	9.2
24	19 "	106	73	11.0	11.9	11.6	8.7
24	20 "	117	78	11.4	12.2	13.3	9.5
24	21 "	111	83	11.7	12.7	12.8	10.5
24	22 "	120	87	12.1	12.9	14.5	11.2
24	23 "	112	89	12.4	12.9	13.8	11.7
24	24 "	103	94	12.7	13.3	13.1	12.7
24	25 "	95	98	13.5	13.8	12.8	13.5
Minimum difference required for significance		13	10	.5	.4	1.6	1.3

In this study cane yields were secured by weighing all millable cane from an inside 40-foot row of cane. After weighing, this cane was run through a 3-roller mill and its crusher juice analyzed for several constituents. Data have been converted to the usual bases and are offered in Table I and in Figs. 11, 12, 13 and 14; combined effects are given in condensed tabular form in Tables II, III, and IV.

Subjected to statistical analyses, the original data supply the following information for further discussion.

ANALYSIS OF VARIANCE
FOR AGE AT HARVEST AND MONTH OF START

Source of variation	Degrees of freedom	Mean squares or variance					
		For TCA		For Y%C		For TSA	
		on plant crops	on ratoons	on plant crops	on ratoons	on plant crops	on ratoons
Age at harvest	7	1601†	1702†	20.76†	12.15†	25.54†	69.99†
Month of start	11	1042*	1588†	6.69†	4.38†	22.04†	47.10†
Interaction	77	334	443	1.54†	2.04†	4.11	11.75†
Error	96	483	316	.74	.55	7.79	5.36
Total	191						
General Average		109	85	12.0	12.7	12.9	10.9
Coefficient of Variation		20.2%	20.9%	7.2%	5.8%	21.6%	21.3%

* Exceeds P = .05 or odds of 19 to 1.
† Exceeds P = .01 or odds of 99 to 1.

Thus the several effects of both age at harvest and months of starting the crop are seen to be highly significant, with the age effect dominating, especially on the Y%C. A few interactions, although significant with respect to error, are perhaps not significant with respect to either main factor separately; hence it is most likely that both of the main effects act independently and are perhaps not differentially influenced by each other. This contention is supported by the yield data which we have combined in condensed tables, No. II to IV which follow:

TABLE II

EFFECTS OF *TIME OF START* AND *AGE AT HARVEST* ON AVERAGE *TONS CANE PER ACRE* (TCA)

Months of start	For plant crops—ages at harvest					For ratoons—ages at harvest				
	18–19 mos.	20–21 mos.	22–23 mos.	24–25 mos.	Avg. for months	18–19 mos.	20–21 mos.	22–23 mos.	24–25 mos.	Avg. for months
Jan.-Feb.	96	110	113	95	103	71	78	72	82	76
Mar.-Apr.	110	121	137	95	115	70	70	83	110	83
May-June	118	125	114	89	111	77	81	101	114	93
July-Aug.	121	129	121	103	118	73	96	119	104	99
Sept.-Oct.	103	98	102	112	104	86	84	83	87	85
Nov.-Dec.	89	105	113	101	102	79	78	71	80	77
Avg. for Ages	106	114	116	99		76	81	88	96	

TABLE III

EFFECTS OF *TIME OF START* AND *AGE AT HARVEST* ON AVERAGE *YIELD PER CENT CANE* (Y%C)

Months of start	For plant crops—ages at harvest					For ratoons—ages at harvest				
	18–19 mos.	20–21 mos.	22–23 mos.	24–25 mos.	Avg. for months	18–19 mos.	20–21 mos.	22–23 mos.	24–25 mos.	Avg. for months
Jan.-Feb.	11.1	10.8	10.9	12.3	11.3	12.4	11.6	11.6	13.2	12.2
Mar.-Apr.	9.9	10.3	11.7	13.2	11.3	11.2	11.2	12.9	13.9	12.3
May-June	10.4	11.7	13.3	14.1	12.4	10.3	12.6	13.6	14.7	12.8
July-Aug.	10.6	12.0	13.2	13.6	12.3	11.7	13.3	14.1	14.3	13.4
Sept.-Oct.	11.9	12.7	13.5	13.4	12.8	12.5	13.4	13.2	13.1	13.1
Nov.-Dec.	11.7	11.9	11.1	12.5	11.7	12.7	12.6	11.9	12.2	12.4
Avg. for Ages.	10.9	11.5	12.3	13.1		11.8	12.5	12.9	13.6	

TABLE IV

EFFECTS OF *TIME OF START* AND *AGE AT HARVEST* ON AVERAGE *TONS SUGAR PER ACRE* (TSA)

Months of start	For plant crops—ages at harvest						For ratoons—ages at harvest					
	18–19 mos.	20–21 mos.	22–23 mos.	24–25 mos.	Avg. for mos.	Avg. TSA/mo.	18–19 mos.	20–21 mos.	22–23 mos.	24–25 mos.	Avg. for mos.	Avg. TSA/mo.
Jan.-Feb.	10.5	11.6	12.3	11.4	11.4	.54	8.7	8.5	8.3	10.9	9.1	.42
Mar.-Apr.	10.9	12.5	15.8	12.4	12.9	.60	7.7	7.8	10.7	15.3	10.4	.48
May-June	12.4	14.5	15.1	12.4	13.6	.64	8.0	10.0	13.7	16.6	12.1	.56
July-Aug.	12.8	15.1	15.6	13.9	14.3	.67	8.5	12.8	16.7	14.8	13.3	.62
Sept.-Oct.	12.2	12.4	13.8	15.1	13.3	.62	10.8	11.2	11.0	11.3	11.1	.52
Nov.-Dec.	10.4	12.3	12.5	12.5	11.9	.55	10.0	9.8	8.5	9.6	9.5	.44
Avg. for Ages	11.5	13.0	14.1	12.9			9.0	10.0	11.5	13.1		
Avg. TSA/Mo.	.62	.64	.63	.53			.49	.49	.51	.53		

Inspection of Fig. 11 clearly shows the higher yields of cane and of sugar, but the poorer quality (Y%C), from the plant crops. In general, both cane and sugar yields which came from crops started in mid-season were superior to those from

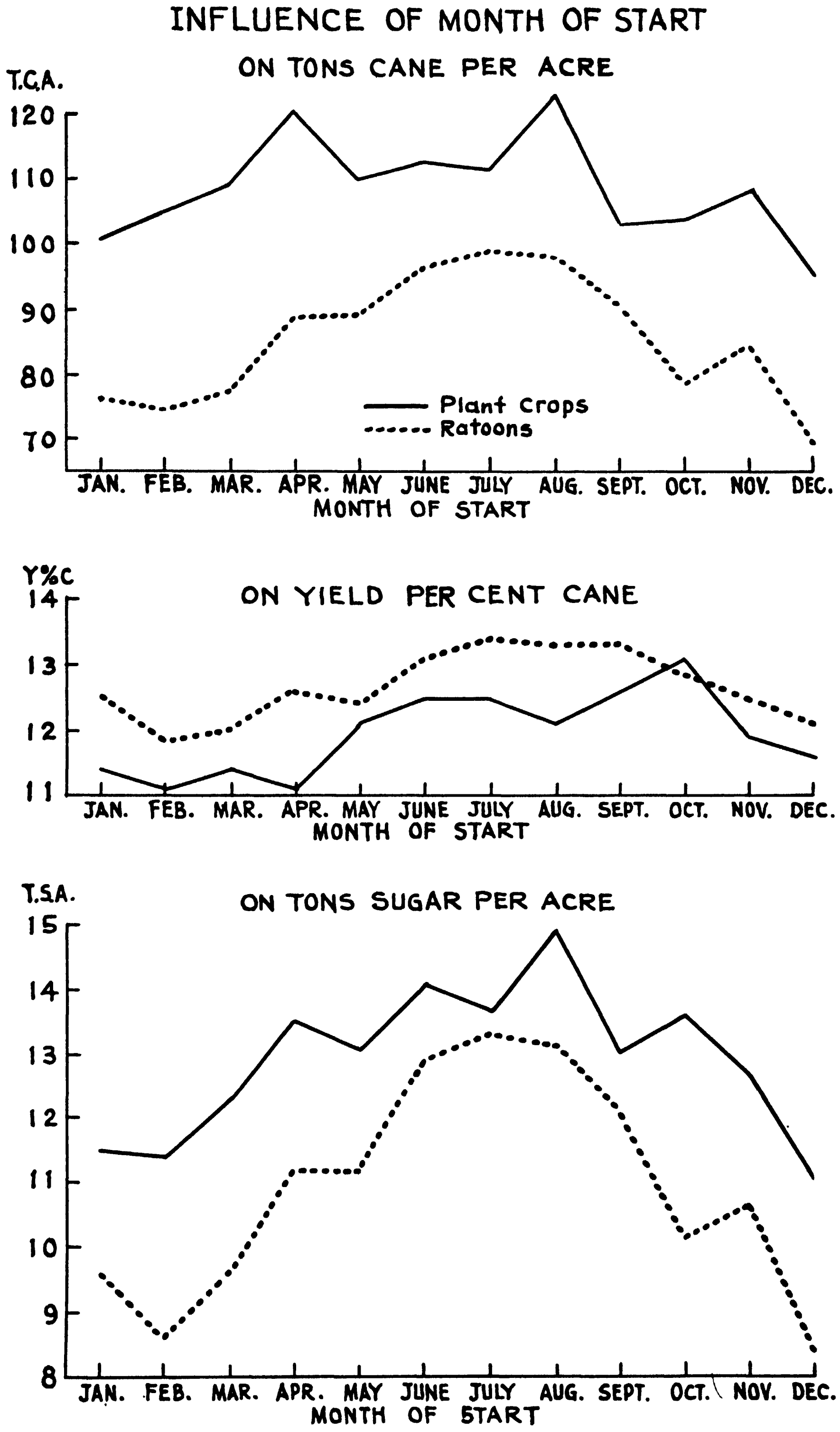
INFLUENCE OF MONTH OF START
ON TONS CANE PER ACRE
T.C.A.
120
110
100
90
80
70
Plant crops
Ratoons
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.
MONTH OF START
Y%C
ON YIELD PER CENT CANE
14
13
12
11
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.
MONTH OF START
T.S.A.
ON TONS SUGAR PER ACRE
15
14
13
12
11
10
9
8
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.
MONTH OF START

Fig. 11

the earlier- and later-started crops; this was also true of the yield per cent cane. Thus, in so far as recoverable sugar yields are concerned, we have pretty good evidence of the superiority of certain seasons in which to start H 109 cane crops in locations similar to Waipio where these canes were grown.

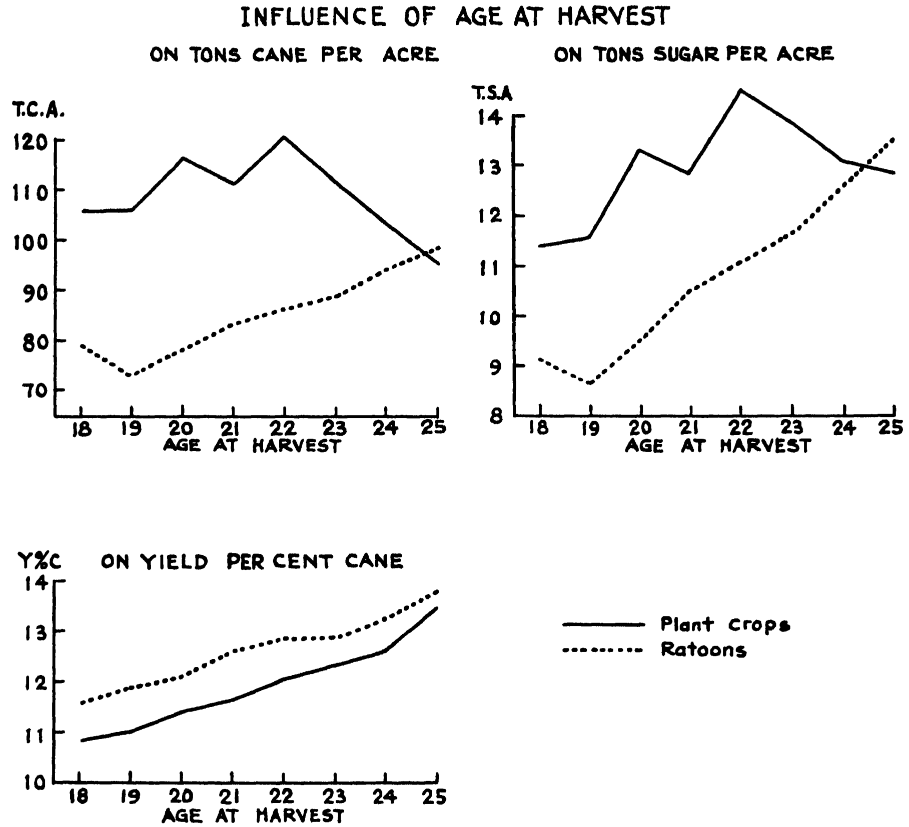

Fig. 12

The influence of age at harvest is shown nicely in Fig. 12. Cane yields from the plant crops fell off sharply after they reached the age of 22 months but this was not a feature of the ratoon yields which continued to increase up to 25 months. These same trends from age at harvest were characteristic of the sugar yields also. The improvements in Y%C reflect the beneficial effects of age upon juice quality, and we believe that this is one of the most significant facts which our investigation has furnished.

Fig. 13 shows that the plant crops had a lower percentage of glucose at harvest than the ratoon crops. Month-of-start effects on plant crops showed higher glucose from crops started early, but little difference was found in ratoons that could be the effect of time of start. The percentage of glucose decreased with age in both plant and ratoons, and at almost the same rate.

The relative rates at which these crops produced cane and sugar between 18 and 25 months is shown in Fig. 14. Tons-cane-per-acre-per-month fell off with increased age in the plant crops but was apparently maintained at a very uniform rate in the ratoons. Sugar-per-acre-per-month dropped sharply after 22 months in plant cane but continued to increase from ratoons up to 25 months.

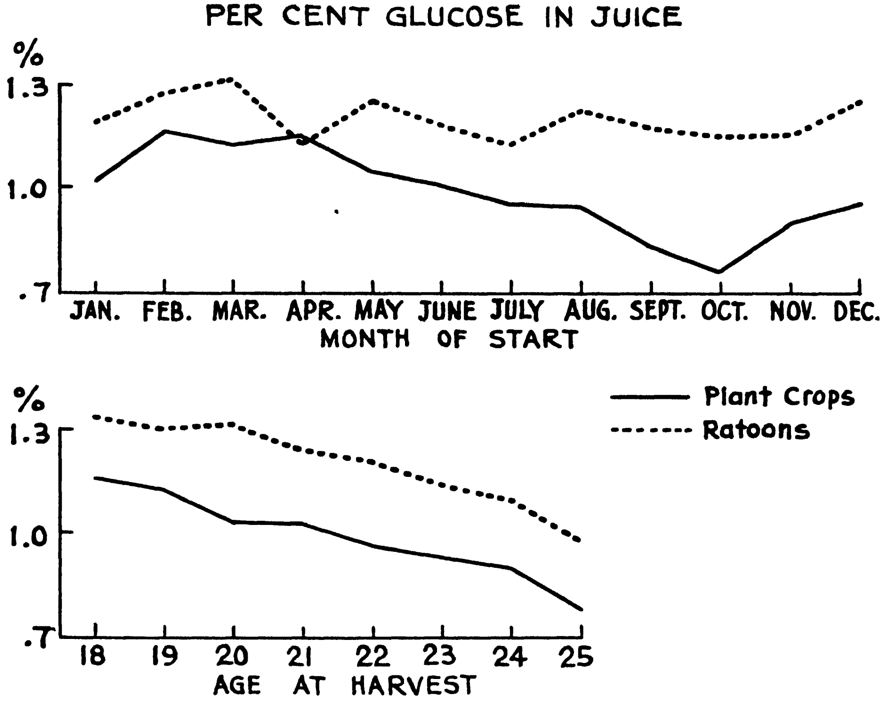

Fig. 13

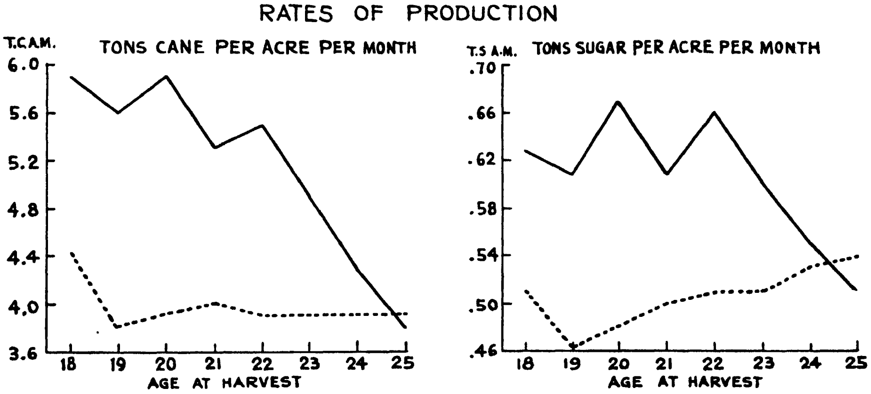

Fig. 14

An interesting relationship is shown in Fig. 15. The light lines show the effects of the month of start and the heavy lines the effects of the month of harvest, on the sugar yields. In these graphs, age at harvest is balanced since all ages from 18 to 25 months are included in each point shown. The relationship is not as clearly seen from the plant crop data as from the ratoons, but it does appear that it will be well to avoid starting and harvesting H 109 crops during the slower growing months of the year.

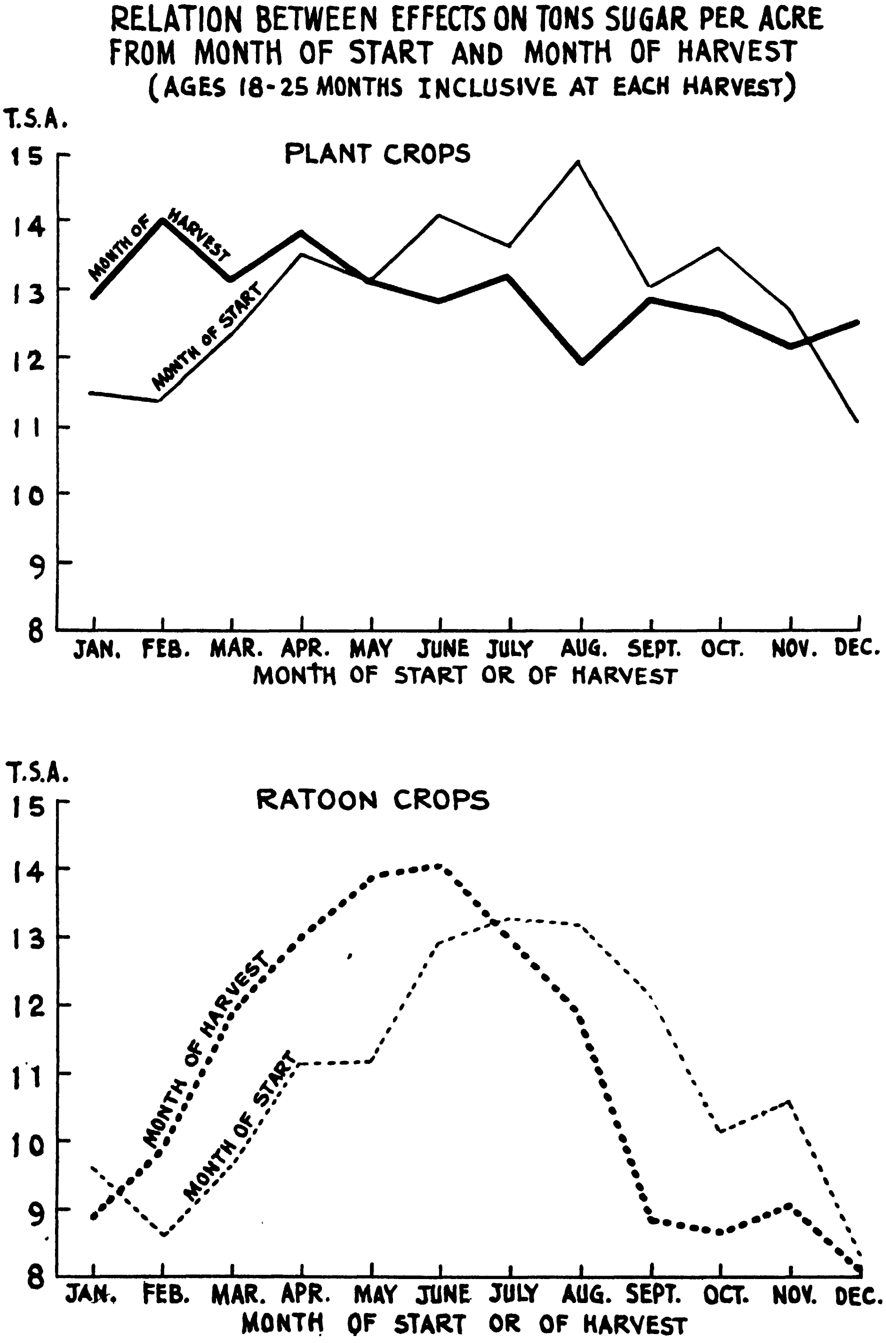

Fig. 15

Summary:

To summarize the data which were collected during this study we present a simple tabulation in which the relationships between the many different measurements are brought together in a brief and easily comprehensible form, as follows:

Measurements	On plant crops	On ratoons
Best age to harvest for sugar yields	22 mos.	25 mos.
Best age to harvest for cane quality	25 mos.	25 mos.
Best age to harvest for cane yields	22 mos.	25 mos.
Best months to start crops for sugar yields	Aug., June, July	July, Aug., June
Best months to start crops for cane quality	Oct., Sept., July	July, Sept., Aug.
Best months to start crops for cane yields	Aug., Apr., June	July, Aug., June
Poorest age to harvest for sugar yields	18 mos.	18 mos.
Poorest months to start crops for sugar yields	Dec., Feb., Jan.	Dec., Feb., Jan.
Miscellaneous statistics*		
Average tons cane/acre, and (tons cane/acre/month)	109 (5.1)	85 (4.0)
Average tons sugar/acre, and (tons sugar/acre/month)	12.9 (.60)	10.9 (.50)
Average yield per cent cane	12.0	12.7
Average % glucose in crusher juice	.99	1.21
Average % P_2O_5 in crusher juice	.026	.027
Average % K_2O in crusher juice	.057	.053
Average % N in crusher juice	.012	.013
All millable stalks at harvest: No. per foot of row	2.92	2.65
Average length	14.0 ft.	12.7 ft.
Wt. per ft. of stalk	.63 lb.	.59 lb.
Non-millable stalks at harvest: No. per ft. of row	.30	.40
Dead stalks at harvest: No. per ft. of row	.64	.96
Selected stalks measured: Length at 8 months	6.4 ft.	7.1 ft.
Length at 16 months	13.1 ft.	13.6 ft.
Length at 24 months	17.4 ft.	18.3 ft.
Monthly elongation of measured stalks	.67 ft./mo.	.68 ft./mo.
Average number of day-degrees	12.2	13.2

* Averages from all ages at harvest and all months of start.

Edible Soybean—A Food Crop for Hawaii

By C. G. LENNOX

The edible soybean assumes a position of prominence as a source of substitutes for animal proteins and oils in Hawaii's program of self-sustenance.

The high protein content of the green shelled beans, quickness in developing a crop, freedom from serious insect pests and diseases, and cheapness of planting, cultivating and harvesting in terms of man-days per ton of green beans, all contribute to the value of the soybean as an emergency food crop.

Success with the year-round production of soybeans in Hawaii hinges principally upon the correct choice of varieties for planting in the different seasons; secondly upon sufficient fertilization with nitrogen and phosphorus.

The production of diversified food crops for local consumption has taken on a new significance for Hawaii since this Territory has become the front line in a war zone. The fact that local production of crops in this category has fallen far below the local consumption is due to the prevalence of insect pests, a climate unfavorable to the crops, and the prevailing economic setup. Economic values need not be considered in a situation where it is a matter of eating or going hungry, but insect pests must be controlled if we are going to grow the crops which they attack, and the climate is, of course, quite beyond our control. If we are to grow diverse food crops, it becomes necessary to select crops which will afford us the necessary nutrients, make a reasonable growth under our climatic conditions and survive the attacks of the insect pests which we are unable to bring under complete control. Among the crops which fulfill these requirements, the soybean appears to rank very high and is one of the most reliable food crops for us to grow to meet this wartime emergency.

THE GROWTH OF SOYBEAN PRODUCTION IN THE UNITED STATES

It is estimated by one authority that the soybean has been highly prized in China for more than 25,000 years. Although introduced into the United States in 1804, it passed unnoticed for the first hundred years with only small plantings in some of the southern states. By 1919 a fairly uniform development was occurring in states east of the Mississippi with considerable prominence in the New England states and some interest in certain southern and mid-western states. The crop was beginning to show some importance in 1924 when approximately one-half million acres were harvested for beans with a production of five million bushels.

The dramatic story of the soybean increase in the United States starts with 1924. Table I shows a consistent doubling of production until 1934 after which it is more than tripled.

TABLE I

ANNUAL SOYBEAN ACREAGES, YIELDS, AND PRICES IN THE UNITED STATES

(Adapted from Kiesselbach and Lyness [7])

Year	Acres harvested for beans	Yield of beans per acre—bushels	Total production—bushels	Average price per bushel paid farmers
1924	448,000	11.0	4,947,000	$2.46
1929	708,000	13.3	9,398,000	1.88
1934	1,539,000	15.0	23,095,000	.99
1939	4,417,000	20.7	91,272,000	.81
1941	5,855,000	18.2	106,712,000	1.47

Note: The standard weight of one bushel soybeans is 60 pounds.

Kiesselbach (*7*) points out that the importance of soybeans in the United States can hardly be overstressed as a vital necessity of wartime production and states that the Secretary of Agriculture has requested a 54 per cent increase in the country's acreage to be harvested for beans in 1942. This will jump the acreage from 5,855,000 acres in 1941 to 9,000,000 acres in 1942. In spite of the fact that the supply is greatest in history, the Chicago cash price for soybeans was 84 per cent higher on January 30, 1942 than the pre-war average of 1935-1939.

It is interesting to examine the position of the United States in the world production of soybeans. Table II shows that in 1935 next to Manchuria the United States was the second largest producer. These figures, however, do not include production in China which according to estimates leads all others. Figures later than 1935 are not available due to war conditions, but judging from the estimated production for 1942 of 140 to 150 million bushels it is expected that the United States will become second only to China in world production of soybeans.

TABLE II

COMPARATIVE WORLD PRODUCTION OF SOYBEANS

(Adapted from Grove [4])

	Bushels 1930	Bushels 1935
U.S.A.	13,471,000	44,378,000
Manchuria (not including China)	196,944,000	141,793,000
Korea	22,989,000	22,401,000
Japan	14,381,000	10,717,000
Netherland Indies	4,692,000	7,448,000

Vegetable oil, industrial oil for paints and varnishes, plastics, and high-protein stock feeds have been the stimuli for increased production so far. Its direct uses for human food have been of minor importance. Burlison (2) lists the products derived from soybeans grown in the United States and actually placed on the market in the United States and Canada during the latter part of 1931:

Food Products

Soybean flour
Soybean meal flour
Refined edible soybean oil
Soybean salad oil
Chocolate bars (30% soybean flour)
Cocoa (up to 60% soybean flour)
Sausages (up to 50% soybean flour)
Bread (7½% soybean flour)
Rolls (10% soybean flour)
Macaroni (20% soybean flour)
Soybean muffins
Soybean cookies
Soybean doughnuts
Vegetable shortening
Infant foods
Diabetic foods
Oleomargarine
Lard substitutes
Filled sweets
Soybean sprouts
Soybean cheese
Soya cream biscuits
La Choy-Soy sauce
Zoybeans (cooked beans)
Bacon and Zoybeans
Zoy Bouillon
Casein gluten flour
No-fat mayonnaise
Fatless spread
Soyex-Malt-Cocoa drink
Soybean milk
Soybean ice cream

Feed Products

Cake or Meal
Commercial feed
Dairy feed
Hog chow
Poultry chow
Dog chow
Calf chow
Rabbit chow
34% protein chow chow
Chick startena

Industrial Products

Paint
Varnish
Enamels
Oilcloth
Linoleum
Printers' ink
Glycerine
Celluloid
Lauxtex plastic wall coat
Lauxein waterproof soybean glue
Lauxein emulsifier
Soap
Core binders
Rubber substitutes
Plastics

SOYBEAN FLOUR AS A HUMAN FOOD

The principal interest of this discussion is the soybean as a human food. Horvath (6) in discussing soybean flour points out that numerous brands were on the market in 1931, but only one of them can claim to have met with real success, because flour from whole ground beans has a peculiar beany taste and cannot be kept or transported on account of its rapid deterioration. It acquires a bitter taste and repugnant odor in a very short time.* The one exception is a flour, developed and patented by Professor Barszeller working in Vienna, in which the obnoxious constituents were eliminated by special milling and fractional distillation. It is completely free from bitter flavor and can be stored indefinitely. This patented soybean flour is called "Soyolk". Horvath reports on the work conducted by numerous nutrition and bakery experts in Holland, Hungary and Austria in which they have tested the value of "Soyolk" and report satisfactorily on its value. A typical report, from F. A. Richter, baking expert of the Nutrition Laboratory of Vienna, states: "We took special care not to deviate from the customary flavor, taste and outside appearance of the various kinds of bread used in different countries (England, Scotland, Wales, Ireland, France, U.S.A., etc.). In none of these tried methods of making bread by adding soya flour in the above proportions could any essential change in flavor, or texture, be discovered in the bread. On the contrary, it improved the flavor of a Viennese roll and gave it a tempting appearance. We can say the same of the dark loaf of Germany, of the American cream cracker biscuit and the English wholemeal loaf."

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* Research in soybean flour during the past 10 years in the U.S. has developed methods of producing good quality flour by cleaning the beans, steaming, drying, hulling, and then milling. LeClerc (8) discusses process of flour making and uses.

The high protein and fat content of soybean flour places it as a valuable meat substitute in emergency rations or low-costs diets. Horvath quotes Dr. Kupelwieser as stating that 1 kg. of "Soyolk" is equivalent in protein to 2.5 kg. lean boneless beef, or 67 eggs, or 13.7 liters of cow's milk. The following is the average composition of wheat and soybean flours and gives an indication of the relative contribution of nutrients by each.

	White Flour* Wheat	Flour* Soybean
Protein	10.8	37.3
Carbohydrate	75.6	9.5
Fat	.9	20.2
Crude Fibre	.3	2.5
Ash	.4	4.7

* Nutritional Charts—Research Department, H. J. Heinz Co.

The work referred to above by Horvath was taken from reports coming from Europe during 1928-1930. Work with the soybean flour in Germany apparently has continued until today it occupies a very important position in German war plans. The following statement appears in the July 1942 issue of the *Nutritional Observatory* (5): "Because of the relative lack of foodstuffs of animal origin in Germany, the Nazis are making the fullest possible use of soy-flour as a food weapon in the present conflict, particularly as a substitute for animal protein. Soy protein is more like animal protein than any other vegetable product. Low cost of the flour is an added advantage. At the end of the Polish campaign Nazi official circles stated that without soybeans it would not have been possible for the German Army to advance so quickly."

A further reference to the importance of soybean flour in the German war effort appears in *Time,* June 15, 1942, in its review of the motion picture *Food.* It states that: "Farmers grow what they are told to grow, and the soybean (twice the strength of meat at a quarter the price) is the armed forces' basic ration. It is mixed into almost every dish the soldiers eat and, *Food* suggests, may even be Hitler's vaunted secret weapon."

CLASSIFICATION OF SOYBEANS

The many varieties of soybeans may be grouped into three special-purpose categories:

1. Forage types which produce a large volume of stems and leaves suitable for hay or green feeding and are comparable with alfalfa in available nutrients.

Two extremes of the soybean varieties planted June 2 on adjoining beds at Kailua and photographed on August 20, 1942. The variety at the left is late-maturing forage type (Java 29) which is just beginning to flower. The variety at the right is an early-maturing vegetable type (Hahto) which flowered on July 14. The beans are now optimum for using as green shelled beans. Note the Chinese rose beetle damage starting on the late-maturing variety while the early-maturing one has set a full crop with little damage.

2. The industrial types which are harvested as dry beans for their high oil and protein content. Most of the acreage planted for dry soybeans in the United States is in varieties of this type.

3. The green-vegetable or edible types which are palatable as human food. They differ from the industrial types in that the beans are larger, easier to cook and do not have a strong, raw bean flavor.

The interest in varieties suitable for green-vegetable beans is of recent origin in the United States. It was only ten years ago that United States agricultural explorers in the Orient made a project of seeking out the varieties that were used solely as green-vegetable or dry edible beans, and were able to collect more than 100 varieties for this country.

The green-vegetable or edible types are the soybean varieties which have promise for Hawaii as a valuable food crop. The discussion in this paper will deal principally with this type.

NUTRITIONAL VALUE OF GREEN EDIBLE SOYBEANS

The edible soybeans are ready for consumption as a green vegetable in 60 to 70 days after planting and will be a source of highly nutritious food soon after any food shortage may be predicted. They can be harvested with existing machinery and readily transported to the centers of population.

Analyses of the Seaweed variety of green edible soybean grown in Hawaii appears in Table III. These analyses agree closely with similar ones made on the mainland.

TABLE III

NUTRIENT COMPONENTS OF GREEN VEGETABLE SOYBEANS, LIMA BEANS, AND STRING BEANS (KIDNEY) IN RAW GREEN STAGE

	Protein %	Fat %	Carbohydrate %	Calories per 100 gm.	Ca %	P %	Fe %
Soybeans (green shelled raw)*...	12.5	5.1	10.0	130	.063	.239	.00283
Lima Beans (green shelled raw)†	7.5	.8	22.0	125	.028	.133	.0022
String Beans (green raw)†......	2.4	.2	6.3	37	.046	.052	.00093

* Adapted from Miller (10). † Nutritional Charts, Research Department, H. J. Heinz Co.

A situation which would call for supporting the Hawaiian population on locally grown food would find a real deficiency in foods sufficiently high in fat and protein for balanced diets. Crops presently under cultivation are low in these nutrients, therefore the problem becomes one of searching out suitable crops to amend this deficiency. The legumes are the principal sources of proteins in the plant kingdom. Table III gives the comparative composition of three legumes which may be grown successfully in Hawaii, while Table IV gives the estimated yields per-acre-per-month of protein and fat. Soybeans lead all others in protein and fat production per-acre-month by a wide margin.

TABLE IV

ESTIMATED YIELDS OF CALORIES, PROTEIN, AND FAT PER-ACRE-PER-MONTH

Legume	Est. yield* lbs./ac.	Months to completion of harvest	Est. yield ac./mo. lbs.	Calories ac./mo.	Lbs. protein ac./mo.	Lbs. fat ac./mo.
Kidney Beans (green string)	5,000	2.3	2174	364,000	52	4
Lima Beans (green shelled).	4,000	4.0	1000	566,000	75	8
Soybeans (green shelled) ...	3,000	2.3	1304	768,000	163	67

* Based on field and experimental experience at Kailua and Waipio substations in 1941 and 1942. Yields on soybeans based on plantings made during months of April to July.

The proteins of legumes in general are of poor biological quality as compared with animal proteins and cannot be taken at their analyzed value in balancing rations. However, the proteins of the soybean are an exception and are ranked on a par with animal and fish proteins in biological value. Sherman (11) points out that the soybean is markedly improved by cooking and biological tests have shown that the protein of soybeans is definitely superior to that of cowpeas when subjected to the heat treatment ordinarily used in preparing them for human food. The protein of several cooked edible varieties very nearly equal casein, the chief protein of milk.

Soybean oil possesses qualities which make it desirable for food and much of the extracted oil is used in the shortening and margarine industries.

The carbohydrate value of soybeans is low, but since this nutrient is available in excess from sugar, sweet potatoes, bananas, and concentrates which are easily stored it carries small importance.

The mineral composition of the green edible soybean is well above that of other beans. Miller (10) points out that the calcium content of the cooked green beans of the Seaweed variety carried .098 per cent calcium, which compares favorably with that of milk. The phosphorous content on the other hand is higher than milk, while the iron content exceeds that of most common vegetables. The green edible soybean is a good source of vitamins A and B_1.

Cartter (3) shows that the percentage and quality of oil are influenced by the existing environment during the entire growth of the plant. Likewise, the percentage of carbohydrate, protein and mineral constituents may be influenced by soil and environment.

THE SOYBEAN IN HAWAII

The edible soybean is not new in Hawaii. The annual report for 1908 of the Hawaii Agricultural Experiment Station states in reference to soybeans: "A green seeded type has been grown in the Kona District of Hawaii for some years." The reports of 1932 through 1935 from the same Experiment Station tell of the importations of many varieties for trial. Preliminary trials were also made on the green-vegetable types.

Cultural Requirements:

Although growing conditions in Hawaii are suitable for a year-round production of most vegetable crops we find the soybean an exception. It is a plant whose time of flowering responds to the length of day rather than temperature.

The soybean is one of a large group of plants which flowers under the stimulus of a long period of darkness. Although the day length of the shortest day in Hawaii is only two and one-half hours shorter than the longest day this is quite sufficient to have a profound effect on the soybean. During the summer season the plants come into flower in exactly the same length of time as recorded on the mainland, but as the days shorten the flowering commences sooner. Nearly all the flowers bloom at the same time on the soybean plant and if the flowering is initiated before a full-size plant has developed, the number of flowers is proportionately reduced. The reduction in number of pods per plant results in a reduced yield per acre. It is this stimulus of the short day resulting in small crops that has retarded the interest in soybeans as a vegetable crop for Hawaii.

Extremes in maturity of green-vegetable type soybeans. Both varieties planted May 20, and photographed August 20, 1942. The variety in the foreground is Hokkaido, an early-maturing type which reached the vegetable stage on August 1. The variety in the background is Giant Speckled, a late-maturing type. It will not reach the green-vegetable stage for fifteen days, and did not produce a heavier crop of green shelled beans than the Hokkaido.

When planted after September the Giant Speckled will develop a small plant about the size of the Hokkaido pictured above.

Varietal Characteristics:

The green-vegetable type soybeans are classified according to maturity under summer length of day. The early-maturing groups are small plants with the pods usually clustered close to the ground. They reach the green-vegetable stage in 60 to 70 days. The medium-maturing groups reach the green-vegetable stage in 70 to 90 days. They are bigger plants and the pods are usually dispersed over the length of the main stem. The late-maturing groups reach the green edible stage in 100 to 120 days. They are large plants from 3 to 4 feet tall with the pods thinly distributed over the upper three-fourths of the plant. The many varieties under trial show a full range of intermediate stages within these three general classifications.

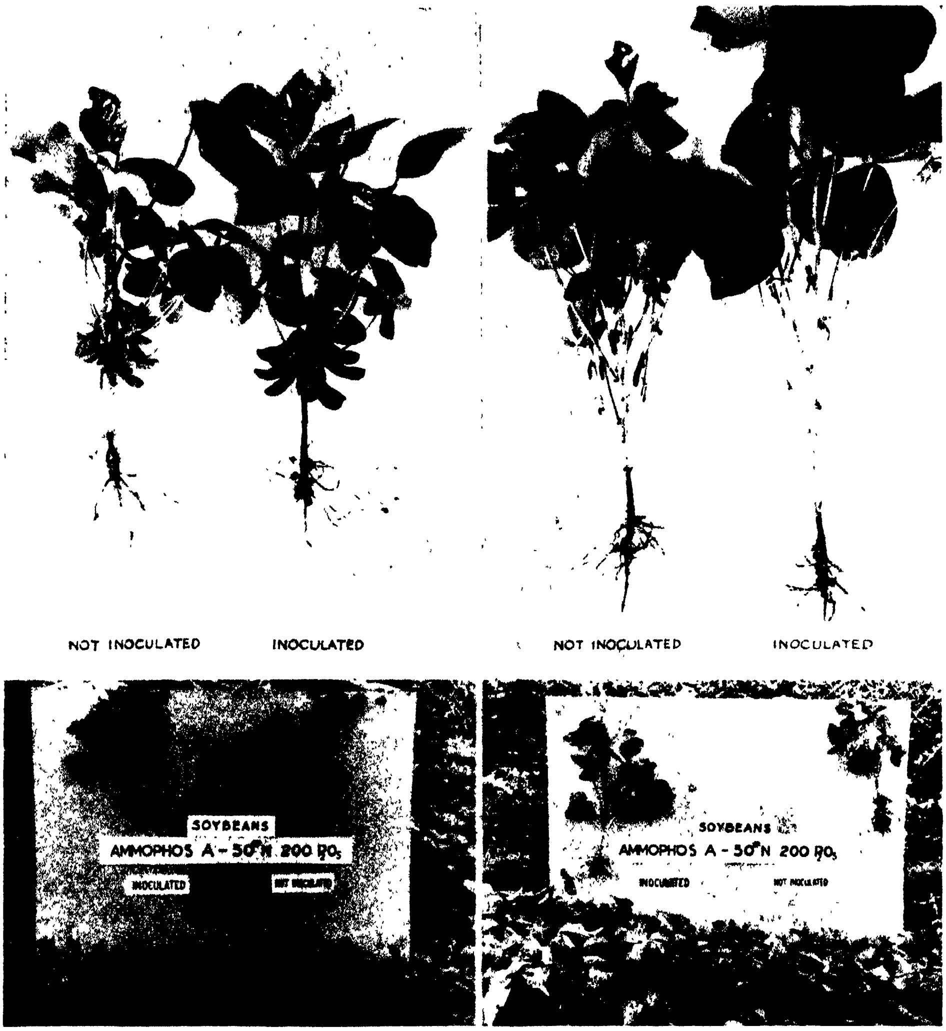
The different varieties planted throughout the year show a changing time of maturity which is an integration of the genetic maturity of the variety and the current length of day. In other words, a late-maturing variety continues to be a late-maturing variety under the shortest day length but matures earlier, while the early-maturing ones are proportionately earlier. The problem of selecting a variety for Hawaiian conditions therefore becomes one of choosing a genetic maturity to compensate for the day length during the season it is to be grown. For early summer planting the early-maturing type should be selected, for midsummer a medium-maturing type, while during late summer and winter months only late-maturing varieties should be planted. By this judicious selection of varieties reasonably good yields may be expected the year-round.

Soil:

The experience so far indicates that an acid (pH 6 or below) soil is not favorable for the best soybean growth. Such a condition is not conducive to the development of nitrogen-fixing bacteria and the plant is not vigorous. Heavy alluvial soils in valley bottoms have given the finest growth and seem well suited to the soybean plant. The red residual soils, typical of leeward sugar cane conditions, have produced equally good crops providing they are deeply plowed, well fertilized and irrigated. The soybean plant although having a small root system is deeply rooted. It sends its roots to a depth of from 3 to 5 feet and responds to well-prepared and deeply plowed seed beds. It is highly reactive to poor spots in the field, such as outcroppings of subsoil, areas underlain by gravel or sand wash, and in fields of spotty soil depth or fertility the locations of the poor areas are brought into sharp relief by a population of soybean plants.

Fertilization:

Nitrogen: The soybean is a legume and if the seed is inoculated with the proper nitrogen-fixing bacteria immediately before planting it will obtain some of its nitrogen requirement from the air. However, it requires available nitrogen in the soil to carry on maximum growth during the first 30 days because the nitrogen released to the plant by the nitrogen-fixing bacteria is not appreciable until nodulation is well advanced. On soils low in nitrogen, especially following a crop of sugar cane, the experience has been that between 50 and 75 pounds of nitrogen per acre must be added. Judging from observation tests at both Kailua and Waipio the nitrogen should be from an ammoniacal source such as ammonium sulphate or Ammophos. Nitrate nitrogen is reported to inhibit the development of nitrogen-fixing bacteria.



Inoculation of soybean seed with the proper nitrogen-fixing bacteria has a more pronounced effect on the late-maturing varieties than on the early-maturing ones. The variety at the left is an early-maturing type, although nodulation has been heavy there is little improvement in yields. The variety at the right is a late-maturing type and is benefiting from the nitrogen supplied by the nitrogen-fixing bacteria. Both varieties planted March 9, 1942 at Waipio.

No appreciable benefits from inoculation have been noted on the early-maturing varieties in the many trials conducted at both Kailua and Waipio. In these varieties the plant reached nearly full maturity in 30 days and was beginning to flower. However, on the late-maturing varieties a very marked benefit from inoculation has been noted. In these cases the plant did not reach the flowering stage until 60 or 90 days from planting and developed 2 or 3 times the vegetative matter that the early-maturing varieties did. It is estimated that these varieties obtained two thirds of their nitrogen requirement from the air and approximately one third from the soil. Inoculation of seed with nitrogen-fixing bacteria was worth while in either case because of the increase in nitrogen in the roots after the crop had been harvested and thereby increasing residual nitrogen for succeeding crops.

The soybean is different from most legumes in that only one tenth of the nitrogen in the plant is in the root system. Thus when most of the plant is removed from the field, as would be done with the edible types in Hawaii, there remains little of the plant material to supply residual nitrogen for the following crop. Besides the small increase in residual nitrogen, Sears (13) points out that land on which a crop of soybeans has just been grown usually "works well and is easily put in shape for seeding of other crops." This is the characteristic residual effect of most legumes. The improved physical condition of the soils also favors the development of micro-organisms which require plenty of oxygen. Sears presents data following a 36-year rotation of soybeans, corn, corn, corn rotation, which show the residual nitrogen, micro-organisms, and yields of corn decrease on successive years planted to corn following a crop of soybeans.

TABLE V

SOIL PROPERTIES IN SOIL AT URBANA, ILLINOIS, PLANTED FOR 36 YEARS IN A SOYBEAN, CORN, CORN, CORN ROTATION

(Adapted from Sears [13])

Year after soybeans	Pounds NO_3* per acre soil	Millions of micro-* organisms per gram air dried soil	Yield corn bushel per acre (36-year average)
First year	27.7	14.5	50.7
Second year	16.4	11.2	46.3
Third year	13.3	9.5	42.3

* Nitrate analyses and micro-organism counts made in 1928. Yield figures are averages for 36 years.

It might be suggested that sugar cane would benefit as corn does after a crop of soybeans since both have somewhat the same feeding requirements.

Phosphate: Phosphate fertilization is second only to nitrogen in importance for securing a heavy crop under Hawaiian conditions. Noticeable benefits have been observed on nearly all soils, some of which are considered high in phosphate by sugar cane standards. The phosphate should be placed in the furrow under the seed.

Potash: No benefits have been observed from potash fertilization on the Experiment Station areas where soybeans have been tested. One of the fields at the Kailua substation which is very low in potash by sugar cane standards (less than 70 pounds per acre-foot) has shown no benefits from potash in repeated N-P-K-observation tests.

Irrigation:

Although the soybean plant is deep rooted and reported as drought resistant on the mainland the experience in the Experiment Station plantings at both Kailua and Waipio is that it needs a liberal moisture supply until the pods are well formed. Deficiency of moisture during the early periods of growth results in a small plant at flowering time and a correspondingly reduced yield.

Planting:

The edible types favored for summer planting are early-maturing small plants and can be planted in rows 24 to 30 inches apart with the seeds spaced 1½ to 3 inches in the row. The same distance applies to the winter planting where the late-maturing varieties are used, since under these conditions the plants attain a size comparable with the early-maturing types in summer time.

Forage types develop large rank plants and should be planted in rows 36 to 48 inches apart. They should only be planted between the months of March and August as earlier or later plantings are sensitive to the day length and mature before developing a worth-while tonnage of green material.

In both cases the seed should be covered to a depth of ½ to 1½ inches, with shallow covering for heavy soils and deeper covering for light open soils. Uniform depth of covering is important since delayed germination means delayed maturity and it is undesirable at harvest time to have scattered areas in the field at different stages of maturity than the general average.

Harvesting:

Edible Types as Green Beans: Most of the pods on the plant are at the same stage of maturity. They are ready to harvest as green beans when the seed is fully swollen and usually remain at this optimum stage for a period of one week to ten days. Some varieties show the approach of this optimum stage by the lower leaves yellowing and dropping, while others maintain a normal healthy leaf system throughout the entire stage and the decision as to maturity must be made by examining the beans in the pods.

Harvesting is done by cutting the main stem at the ground level and sending the entire bush with its load of pods to the market. If the culture has been a flat one or the plants have been slightly hilled up they can be cut mechanically with a grain or hay cutter. Harvesting by hand with a stout grass knife or cane knife is a cheap operation and results in a cleaner product for the market. Stripping the pods from the plant is an operation left to the purchaser.

Edible Types as Dry Beans: After the plant has passed the stage for harvesting as green beans the leaves begin to yellow and fall off while the pods turn yellow and then a dark brown. As the plant reaches its last stage of maturity it is bare of leaves. The pods of most of the edible types will tend to shatter in the field when they become fully dried with a resulting loss of beans. To avoid this they should be cut when the beans reach a "hard dough" stage and piled in windrows and allowed to cure for five or six days. If the cutting is done in the morning when the plants are damp there is less loss from shattering of mature pods. An ordinary grain thresher can be used for threshing out the beans if the cylinder speed is reduced to 2,300 to 2,500 feet per minute. Sjogren (12) recommends that the number of rows of teeth in the lower concave be reduced to one or two and blanks substituted. This will give complete threshing and reduces the percentage of broken beans.

Forage Types for Green Feed, Hay or Silage: The forage types reach their optimum protein content when the pods are just beginning to fill. However, harvesting can be done at any time after the pods have set and until the leaves begin

As the beans on the soybean plant reach full maturity the pods turn brown and the leaves drop off. This planting of the early-maturing edible variety "Seaweed" will be ready for threshing in two weeks.

This forage variety (Java 29) was planted on June 2 at Kailua and photographed on August 20, 1942. It will be prime for cutting for green feeding or silage any time from August 20 to September 15. Forage types do not produce sufficent green material to warrant planting if planted later than July or earlier than March.

to yellow. In the summer time this is a period of 30 to 50 days. The forage types should be grown on flat culture or with irrigation furrows between the rows so that they can be harvested and raked mechanically.

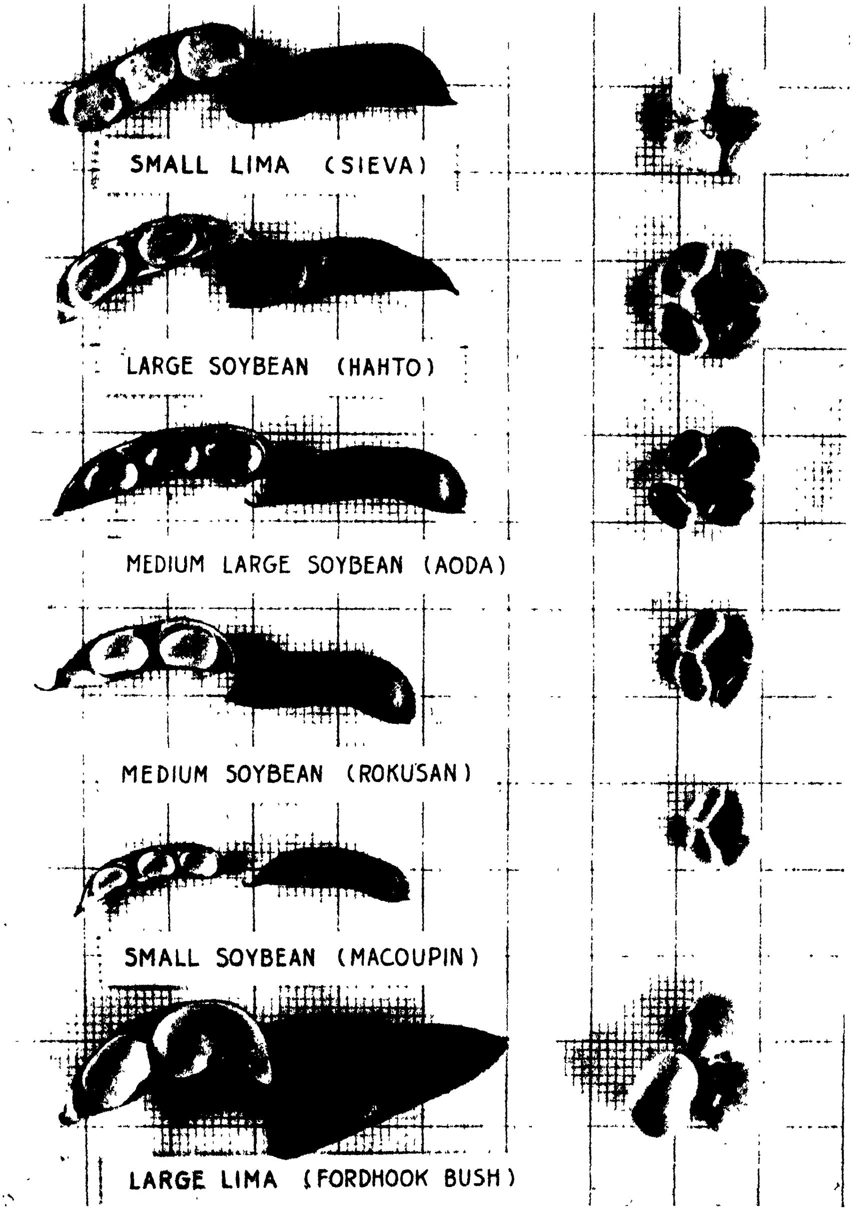
Insect Pests:

The Chinese rose beetle *(Adoretus sinicus)* is the most serious pest of soybeans. Its damage is most pronounced on the late-maturing varieties and can increase to such an extent as to materially reduce yields. The early-maturing varieties, however, have set their crop before damage becomes extensive and yields are not affected. When late-maturing varieties are matured early under the influence of the short day the rose beetle damage is not serious.

A heavy-bearing soybean variety from South Africa. It is a late-maturing type and consequently suffers from Chinese rose beetle damage to the leaves. This is not an edible type, but belongs to the group whose beans are used in industry.

Doves have constituted the only other pest that has done damage of serious proportions in Hawaii. Their damage is done during the two or three days when the swollen cotyledons are exposed above the ground before the first leaves unfurl. In small plantings this damage may be considerable, as the doves will nip off every cotyledon in sight.

The green leafhopper *(Empoasca solana)*, the bean capsid *(Pycnoderes quadrimaculatus)*, and the white fly *(Aleurodes vaporariorum)* which at times cause so much damage to both kidney and lima beans have never been noted as serious on the soybean. The bean-pod borer *(Maruca testulalis)* which damages both kidney and lima beans has never been noted on the soybean. The dry beans are always free of bean weevil damage (Bruchus species) which has been observed to infest



Some varieties of soybeans have a bean as large as the baby lima bean. The large bean varieties usually rank highest in palatability tests and also offer less difficulty in shelling out after cooking.

kidney beans before and after threshing. This observation coincides with the recommendations of Boswell (1) that dry edible field bean crops should not be attempted in regions threatened with midsummer showers because of unavoidable infestation by bean weevils. A moth *(Ephestia cautella)* will attack the dry beans when stored in the open.

The soybean is not beset with the insect problems confronting both kidney and lima bean production and it dries to a moisture percentage which will permit storage.

Diseases:

The experience gained so far shows the soybean to be free of serious diseases in Hawaii.

Bacterial blight caused by *Bacterium glycineum* has been noted on nearly all varieties. It is manifested by angular spots which are at first translucent, then yellow, and finally a dark brown which gives the general appearance of rust on the leaves. The spread of the disease is favored by frequent showers or overhead irrigation. In no cases has it assumed serious proportions on the early-maturing edible types. However, on some forage varieties which are late maturing the disease has gained some headway and it is important that the degree of susceptibility be determined for a variety before it is planted to a field scale.

Variety Selection:

The work of the Experiment Station on the soybean has been primarily one of testing hundreds of varieties and selections submitted by mainland correspondents.* As the project has progressed a clearer conception of standards required for edible soybeans in Hawaii has been developed. With the planting program continuing throughout the year it has been possible to classify varieties as to their suitability for spring, summer, late-summer, fall or winter plantings.

Considerable emphasis is placed on early maturity, since it is the best insurance against rose beetle damage and disease, and also is the quality required of a food crop for an emergency. The bean size also receives emphasis, with varieties of large bean size being preferred to ones of small bean size.

Taste tests are conducted on cooked beans of all promising varieties. In general it has been shown that the varieties with large beans are rated excellent in flavor and texture, while those with small beans are only fair to poor.

The elimination of poor varieties is still in progress, but at the present writing the following would be named as among the best for planting at the different seasons of the year:

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* **Acknowledgment: Dr. W. J. Morse, Senior Agronomist, Division of Forage Crops and Diseases, U.S.D.A., has been most generous in supplying the project with many varieties of edible soybeans.**

Months to Plant	*Variety*
March and April	Hokkaido
	Emperor
	Imperial
May and June	Hahto
	Sac
	Seaweed
July and August	Hokkaido
	Emperor
	Imperial
	Hahto
September through February	Seminole
	Giant Speckled

Harvesting Results from Preliminary Yield Trials:

In preliminary yield trials the following technique is used in securing the yields of green shelled beans per acre:

When a variety reaches the optimum green vegetable stage a ten-foot section is selected from the center line of a three-line plot where the stand is uniform. All plants are cut at ground level and weighed. A random subsample of one fourth of the plant population is taken from which all the pods are stripped. The percentage of total weight which is due to beans and pods is calculated. A second subsample of 20 pods chosen at random is then taken. The beans are shelled out and the percentage of bean weight to total pod weight is calculated.

The following data give examples of the yields obtained from varieties planted in a preliminary test at Waipio on May 20, 1942. It will be noted that the yields from the late-maturing varieties are not commensurate with the length of time required to develop them.

Variety	Days to harvest	Lbs. gr. plants/ac.	% Pods	Lbs. gr. pods/ac.	% Beans	Lbs. gr. shelled beans/ac.
Hahto 22	67	15,800	53	8400	53	4,450
Hahto 2b	74	12,100	62	7500	56	4,200
Sac	67	12,200	56	6820	56	3,960
Hokkaido	67	14,800	52	7700	52	4,000
Imperial	67	14,200	49	6950	53	3,700
Emperor	67	16,800	43	7230	52	3,750
Seaweed	74	15,200	47	7180	51	3,650
Macoupin	83	14,800	48	7110	54	3,850
Seminole	101	22,700	39	8850	45	3,970

Supplementary data are also taken on each variety at harvest which are of value in interpreting their relative goodness.

Variety	Plant size	Bean size	No. plants per 10' section	No. pods per plant	No. beans per pod	Palatability of cooked beans
Hahto 22	Medium	Medium-Large	30	..	...	Excellent
Hahto 2b	Medium	Large	37	38	2.2	Excellent
Sac	Medium-Small	Large	26	34	2.1	Excellent
Hokkaido	Medium	Large	28	30	2.0	Excellent
Imperial	Medium-Large	Large	28	27	1.7	Excellent
Emperor	Medium-Large	Large	28	28	2.2	Good
Seaweed	Medium	Medium-Large	30	31	2.1	Good
Macoupin	Large	Small	35	37	2.4	Poor
Seminole	Very Large	Medium-Large	30	42	2.2	Good

A replicated test planted in the same field at Waipio on July 13, 1942 and laid out in a checkerboard arrangement with plot sizes the same as used in the preliminary test gave the following yields at 65 days after planting:

Variety	No. plots	Lbs. green shelled beans per acre	Gains lbs./ac.	Odds (by Student)
Sac	6	4342	725	12:1
Bansei (check)		3617		
Emperor	5	3790	75	....
Bansei (check)		3715		

It is interesting to note that per-acre-yield of green shelled beans is essentially the same in the July 13 planting as in the May 20.

Culinary Suggestions:

Directions for cooking and shelling green soybeans:

The green pods of the soybean are difficult to open and the beans cannot be shelled out like lima beans or peas. This difficulty is avoided by first cooking the beans in their pods and then shelling.

After washing the pods they should be covered with boiling water and allowed to boil slowly for one to one and a half hours. Add about two teaspoons of salt to a quart of water.

The shelling operation is easy after the beans are cooked. Drain and allow pods to cool. To shell out the beans pick up the pod and hold with both hands over the container which is to receive the shelled beans. Break the pods across the middle with one motion and squeeze out the beans. The green shelled beans can be served in any of the many ways used to serve green lima beans or peas.

Recipes for Dry Soybeans (14):

In cooking dry soybeans, they should be soaked in plenty of water for 3 or 4 hours, the water replaced by fresh water and cooked until soft. It generally takes longer to cook soybean's than navy beans. It is preferable to cook them in a pressure cooker for 30 minutes at a pressure of 15 pounds. The time and pressure vary with the variety of bean.

Soybean Milk: Soak one pound of dry beans in water for 3 or 4 hours and discard the water. Wash the beans with water several times, grind the moist beans as fine as possible, using water to assist. Add water to make the mixture 1 gallon, and strain. The strained liquid is heated to about the boiling point, preferably in a double boiler, for 15 to 30 minutes. Sugar and salt are added to taste. Keep in cool place.

Soybean Cheese: Proceed as in making milk to the point of heating the strained liquid. The strained liquid is heated to about 190° F., but not to the boiling point. At this temperature dilute acetic acid or vinegar is added just to complete coagulation. If a comparatively low temperature is used, more acid is needed and the cheese is finer; if the liquid is nearly boiling, the cheese formed is in larger and harder masses. This is strained out and washed free from acid. Salt to taste. This cheese is rather mild in taste but is used in making croquettes, salads, sandwich spreads and other products.

Roasted Soybeans: (Method I) Soak dry soybeans overnight, or until completely swollen. Dry the beans between towels and fry in deep fat, a few beans at a time, for 5 to 8 minutes depending upon the size of the beans (temp. 350° F.). When they are slightly brown and crisp, drain, salt and use as salted peanuts would be used.

(Method II) Soak washed beans overnight. Boil them for one hour in salted water, spread in a shallow pan and roast in a moderate oven (350° F.) until browned. Sprinkle them with salt while still warm.

Soybean Nut Butter: Grind about 2½ cups of roasted soybeans and mix with about 2 tablespoons of purified soy oil or salad oil.

Baked Beans: 4 cups cooked soybeans
2 cups tomato pulp
½ medium sized onion—minced
2 slices green pepper—cut fine
3 large stalks celery—cut fine
½ tsp. salt.
1 tbsp. molasses
Bacon

Cook vegetables, add beans, salt and molasses. Cover with thin slices of bacon Bake slowly.

Soy Loaf: 2 cups soybeans cooked and mashed
½ cup bread crumbs
2 eggs
½ cup milk
2 tbsp. grated onion
4 tbsp. butter or shortening
½ cup water
1 tbsp. celery salt

Mix all ingredients. Put into a buttered pan and bake for 20 to 30 minutes. Serve with tomato sauce.

Soy Loaf No. 2:
1 cup cooked rice
1 cup cooked soybeans
2 hard boiled eggs—chopped
1 cup milk
1 tbsp. oil
1 scant cup bread crumbs
½ tsp. poultry seasoning
1 tbsp. minced onion
Salt to taste.

Mix and bake in a greased pan.

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Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
MARCH 15, 1942 TO JUNE 15, 1942

Date	Per pound	Per ton	Remarks
March 15,-June 15, 1942..............	3.74¢	$74.80	Philippines

THE HAWAIIAN PLANTERS' RECORD

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A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

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Nitrogen Studies

Comments by Dr. A. L. Dean

In this issue of the *Record* are two papers, each summarizing the results of large numbers of analytical determinations and each addressed to expanding our knowledge of the relations of nitrogen fertilization to cane growth and sugar yields. The results are not altogether in harmony, which may cause mental distress in some minds. It may be assumed that the laboratory work of chemical analyses has been competently done and that such apparent differences as exist arise from other causes.

It is, of course, true that one set of data was obtained from 31–1389 cane and the other from 32–8560. One hesitates, however, to place too much emphasis on that difference. Rather, one is inclined to look at the sampling methods for an explanation of such differences as the data present.

Sampling is one of the most difficult problems to solve in many types of chemical control. One cannot, for example, walk up to a 10,000-ton pile of coal, pick up a lump or two, analyze the sample and expect to get any reliable idea about the average composition of the pile. Sampling ore presents a similar problem and we are all familiar with the difficulty of getting a truly representative soil sample from an area of any substantial size.

Dr. Clements uses "five *selected* plants representing the average of the stand of those plants presumed still to be there at harvest" as material from which samples are prepared for analyses. Growth measurements were made on 20 "pilot plants in each plot" using the same plants throughout the cycle. From the crop harvest, the plants used for analytical purposes, and the growth measurements, the tonnages of cane per acre and the amounts of nitrogen per acre in the crop at various stages are computed. Dr. Clements explains that he uses the term plant to denote a single stalk with its green top and does not imply the whole stool.

Mr. Borden, on the other hand, cuts five feet of cane row and uses all the cane standing therein as the basis both for calculations and samples for analyses.

Results obtained by such different methods would scarcely be expected to be wholly consistent, but both may add to the sum total of our knowledge.

It is well to have clearly in mind the objectives of the two studies. Dr. Clements is satisfied that the cane plant itself is the best guide to follow in nitrogen fertilization. He is therefore concerned in finding a part of the plant the nitrogen content of which will be a reliable index of the nitrogen status of the whole plant and of the field. He presents evidence in the first part of his paper to show that he has found such index tissues. The next step is to correlate results from sample cane stalks with the progress of the field in order to develop a practical method for field control of nitrogen fertilization, and the second part of his paper is his contribution to that end.

The work of Mr. Borden and his collaborators is addressed to expanding our knowledge of the composition and behavior of the whole body of cane in a field throughout a crop with special reference to nitrogen relationships. Only indirectly does that work involve the use of the cane itself as a guide to fertilization. The methods followed indicate that a substantially larger quantity of nitrogen was present in the total cane blanket of the field than the amounts indicated by Dr. Clements to be in the crops he was studying. Borden's data also tend to emphasize the soil contribution of nitrogen and to suggest that soils more highly endowed with organic matter and nitrogen may make highly significant amounts of nitrogen available to growing cane.

One thing seems clear—we have some distance yet to go before arriving at a satisfactorily complete understanding of nitrogen-sugar cane relationships. I am again reminded of a comment once made to me by Russell H. Chittenden, the pioneer of biological chemistry in America. Said he, "A properly authenticated scientific fact is good for all time, what it means is subject to continuing revision in the light of new knowledge."

Nitrogen and Sugar Cane

The Nitrogen Index and Certain Quantitative Field Aspects*

By Harry F. Clements and S. Moriguchi

It has already been shown that yields and quality of sugar cane are correlated very closely with the amount of atmospheric energy available to a crop. Because of the variation in climate from season to season and from year to year, as well as in the abilities of a crop to take maximum advantage of the available energy, it is clearly apparent that the manipulation of moisture and fertilizer elements by the grower must be based upon the needs of the crop as reflected by it. In Part I of this paper evidence is presented showing that the nitrogen level of the elongating cane blades or of the green-leaf cane blades serves as a very reliable index to the nitrogen level of the plant itself. In Part II certain quantitative aspects are presented which show the crop absorption of nitrogen applied to the soil. Two cases are presented in which nitrogen was applied empirically and two cases in which it was applied according to the apparent needs of the plants in relation to the atmospheric energy available.

INTRODUCTION

Although it is recognized that no one essential factor in a plant's metabolism can be wholly isolated from the others, it is nonetheless desirable and necessary to view each factor before attempting to gain a concept of the whole as affected by its various parts—particularly those parts which under field conditions are subject to manipulation. Such factors as moisture and the soil elements, particularly nitrogen, phosphorus, potash and at times certain other elements when supplied in proper amounts, enable the plant to take maximum advantage of the atmospheric energy into which it projects itself. Before it is possible to provide the proper amounts of each of these to a crop, it is necessary to select an index tissue which can be used to follow the levels of each factor as the crop grows. Such a tissue must reflect in a high degree of correlation the levels within the whole plant†, for as the absorption and utilization of any factor varies, such variations should be reflected by the index tissue. It is the purpose of this paper to establish the tissue which can be used simply and easily to gain a measure of the nitrogen level within the sugar cane plant and secondly, to present certain data collected from field-grown crops which suggest the amounts of nitrogen contained by the growing crop. Similar reports will appear shortly dealing with potassium, phosphorus, calcium, and available carbohydrates.

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† In this paper, the term "plant" is used to denote a single stalk with its green top and does not imply the whole stool.

Part I

NITROGEN INDEX

The concept of using leaves as index tissues for nitrogen, potash, and phosphorus as well as other elements apparently dates back to 1869 to the work of Isidore Pierre (9) who noted that there were changes in the composition of leaves associated with differences in environment. The development and application of "diagnostic foliare," however, is credited to two other Frenchmen, Henri Lagatu and Louis Maume, who began their researches on the grape in 1923. Since then they have published many papers developing and applying the principles of foliar diagnosis (6, 7, 8).

In 1937, Thomas (11) of the Pennsylvania Agricultural Experiment Station began a series of papers dealing with the principles and practices of foliar diagnosis as applied to fertilizer-requirement studies, using a variety of plants ranging from herbaceous crops such as potato (12) and corn (13) to arborescent plants such as apple (11). In addition to using the principle in establishing evaluation of the N-P-K unit, both in its quantitative and qualitative aspects, he has recently applied it to similar evaluation of the Ca-Mg-K unit (14). In all of these studies leaves of the same morphological age serve as the indicator of the various elements being measured.

Before it will be possible to evaluate these ideas as aids in the solution of problems met in the culture of sugar cane, it is necessary first to select the correct index tissue.

EXPERIMENTAL

The variety of sugar cane 31-1389 was planted and grown, as already described, at Kailua, a place of low light intensity and at Waipio, a place of high light intensity (1). Approximately each month growth measurements and collections of plants were taken. From each of the fourteen plots (both plant crop and first ratoon) five *selected* plants representing the average of the stand of those plants presumed still to be there at harvest were taken and divided into their several parts as already described (2). Green weights and dry weights were obtained and the material was ground in a Wiley mill and stored for analysis. The total nitrogen of each plant part was determined by use of the official Kjeldahl method without modification for nitrates, which do not normally appear in the above-ground parts of this plant.

The parts of the plant used in these studies are as follows: three-internode units of the leafless cane stem numbered acropetally, and the green top divided into the spindle cluster (leaves 1 and 2—counting the emerging spindle leaf as No. 1 and all the included embryonic leaves down to within 5 inches of the stem tip), elongating cane blades (leaf blades of leaves 3, 4, 5, and 6), elongating cane sheaths (sheaths of leaves 3, 4, 5, and 6), green-leaf cane blades (all living leaves below No. 6), green-leaf cane sheaths (sheaths of leaves below No. 6), meristematic material (including the meristem of the stem severed below the node to which leaf No. 2 is attached and including five inches of meristematic leaf bases), elongating cane (the elongating portion of the stem between the nodes carrying leaves Nos. 2 and 6), the green-leaf cane (that portion of the cane between node of leaf No. 6 and that carrying the oldest living leaf, inclusive).

In some of the tables of data which follow, the nitrogen content of the whole plant, green top, and meristematic material and elongating cane is reported. These values are calculated, weighted values obtained from the analysis and weights of the several parts.

DATA

As in previous papers of this series, it is not necessary to present the data of every plot used, even though all such data are statistically treated later on. The nitrogen values for the various plant parts have already been reported for Plots A at Kailua and Waipio (1). It is useful for this paper to present similar tables for Plots C at Kailua and Waipio as well as for the ratoon crops of Plots RA at Kailua and Waipio, and Plot RB at Waipio.

Casual inspection of the data from Plot C at Kailua (Table I) reveals a high nitrogen level throughout the plant as compared with Plot C at Waipio (Table II). Similar inspection of Plot RA at Kailua (Table III) shows a markedly lower general level than in Plot C for Kailua and more nearly comparable to the data for Plot C at Waipio. Plots RA and RB at Waipio (Tables IV and V) are the lowest of all. (Although the actual culture and yields are of no concern in this paper it may be stated that Waipio Plot C received 216 pounds of nitrogen and yielded 13 tons of sugar, Kailua Plot C received 160 pounds of nitrogen and yielded 7.1 tons of sugar, Kailua Plot RA received 100 pounds of nitrogen and yielded 6.0 tons of sugar, while Waipio Plot RA received 170 pounds of nitrogen and yielded 15.1 tons of sugar, and Waipio Plot RB received 180 pounds nitrogen and yielded 16.3 tons of sugar.) Here, we are concerned only with the analysis of a volume of data including plants very high in nitrogen as well as plants, though highly productive, which are very low in their nitrogen composition. It should be possible from such data to obtain a useful and accurate index tissue, one which will reliably indicate the nitrogen levels of plants grown at different light intensities, as well as those grown at different levels of soil nitrogen.

Before proceeding with the selection of the nitrogen index tissue, it is necessary further to inspect Tables I to V. It is quite apparent that each tissue has a rather characteristic amount of nitrogen. The meristematic material, as may be expected, has the highest level, followed by the elongating cane. In other words, in the region of the plant where growth occurs, the nitrogen content based on dry matter is highest. The green, leafy tissues of the plant, the spindle cluster and the two blade samples are next in order, and although they are of the same general range,

TABLE I

TOTAL NITROGEN—% DRY MATTER

KAILUA PLOT C

Part	1939									1940								
	Apr. 21	May 26	Jun. 27	Jul. 23	Sep. 2	Sep. 30	Oct. 28	Nov. 24	Dec. 27	Feb. 2	Mar. 9	Apr. 13	May 18	Jun. 21	Jul. 27	Aug. 31	Oct. 5	Nov. 9
Meristem	3.30	2.47	2.95	2.33	2.27	3.47	2.86	3.03	3.62	3.30	2.94	3.28	3.36	2.78	1.48	3.46	2.62	3.28
Spindle cluster	1.62	1.22	1.03	1.00	.86	1.16	1.12	1.16	1.08	1.10	1.06	1.00	1.02	.92	.75	1.06	1.06	1.00
Elongating cane blades	1.80	1.37	1.17	1.22	1.07	1.21	1.24	1.37	1.26	1.16	1.27	1.13	1.09	.98	.92	1.11	1.17	1.19
Green-leaf cane blades	1.75	1.28	1.07	1.10	.91	1.05	.98	1.04	1.01	1.07	1.01	1.11	1.01	.85	.82	.97	.89	1.07
Elongating cane sheaths	.64	.44	.39	.42	.38	.49	.50	.51	.54	.51	.44	.46	.47	.39	.34	.47	.48	.45
Green-leaf cane sheaths	.57	.43	.34	.36	.33	.32	.33	.38	.38	.41	.36	.36	.36	.32	.32	.32	.33	.23
Elongating cane	2.92	1.40	1.36	.99	1.01	1.55	1.35	1.41	1.38	1.69	1.38	1.46	1.74	1.11	1.01	1.64	1.38	1.50
Green-leaf cane	1.33	.73	.42	.52	.41	.47	.53	.52	.45	.56	.58	.56	.56	.32	.33	.40	.38	.31
Top internodes			.41	.52	.46	.41	.44	.63	.49	.46	.47	.45	.45	.32	.34	.34	.27	.31
16th 3 internodes																	.29	.30
15th 3 internodes																	.29	.30
14th 3 internodes																.31	.29	.30
13th 3 internodes																.42	.31	.26
12th 3 internodes															.37	.34	.30	.26
11th 3 internodes														.42	.40	.31	.24	.25
10th 3 internodes													.47	.42	.41	.32	.23	.23
9th 3 internodes													.36	.39	.39	.29	.18	.21
8th 3 internodes												.35	.39	.34	.33	.25	.16	.16
7th 3 internodes										.42	.40	.38	.39	.31	.28	.20	.14	.15
6th 3 internodes										.40	.42	.34	.37	.33	.25	.20	.12	.15
5th 3 internodes									.49	.43	.47	.37	.38	.33	.24	.19	.11	.15
4th 3 internodes								.54	.47	.45	.44	.40	.36	.31	.22	.18	.10	.17
3rd 3 internodes					.51		.46	.57	.45	.37	.39	.38	.37	.30	.22	.16	.09	.15
2nd 3 internodes				.67	.64	.46	.47	.68	.43	.33	.36	.37	.37	.28	.22	.13	.09	.13
1st 3 internodes			.51	.82	.99	.52	.62	.86	.48	.41	.40	.41	.42	.30	.23	.12	.13	.13

TABLE II

TOTAL NITROGEN—% DRY MATTER

WAIPIO PLOT C

Part	1939									1940								
	Apr. 20	May 25	Jun. 26	Jul. 22	Sep. 1	Sep. 29	Oct. 27	Nov. 25	Dec. 26	Feb. 1	Mar. 8	Apr. 12	May 17	Jun. 20	Jul. 26	Aug. 30	Oct. 4	Nov. 8
Meristem	3.11	3.29	3.53	3.36	2.79	3.38	2.82	3.03	3.30	2.82	3.36	2.75	3.60	2.54	2.66	3.44	2.84	2.48
Spindle cluster	1.45	1.03	1.15	1.11	1.08	1.13	1.13	1.19	1.02	.95	1.00	.85	1.07	.87	.89	.88	.86	.75
Elongating cane blades	1.57	1.02	1.16	1.21	1.12	1.13	1.19	1.25	1.20	1.05	.97	.88	.90	.91	.86	.91	.93	.83
Green-leaf cane blades		.99	.95	.93	.86	.89	.96	.87	.96	.98	.85	.73	.78	.71	.68	.66	.69	.68
Elongating cane sheaths	.48	.39	.47	.46	.42	.45	.49	.47	.46	.43	.38	.35	.38	.41	.38	.38	.35	.29
Green-leaf cane sheaths		.29	.31	.32	.31	.34	.37	.33	.29	.35	.29	.27	.30	.30	.27	.25	.27	.25
Elongating cane	1.13	2.04	1.26	1.43	1.06	1.48	1.44	1.18	2.03	1.74	1.54	1.52	1.63	1.72	1.42	1.55	1.38	1.41
Green-leaf cane		.56	.38	.33	.34	.37	.38	.39	.41	.52	.43	.38	.48	.43	.43	.38	.28	.32
Top internodes				.22	.25	.30	.29	.29	.23	.47	.29	.32	.37	.33	.38	.19	.20	.20
17th 3 internodes																	.23	.18
16th 3 internodes																	.24	.19
15th 3 internodes																	.23	.17
14th 3 internodes																.17	.20	.14
13th 3 internodes															.28	.19	.20	.13
12th 3 internodes													.26	.33	.26	.18	.18	.12
11th 3 internodes													.30	.28	.23	.18	.18	.14
10th 3 internodes													.32	.24	.21	.17	.17	.13
9th 3 internodes												.26	.31	.18	.18	.15	.15	.11
8th 3 internodes											.25	.23	.27	.17	.12	.11	.11	.10
7th 3 internodes										.30	.19	.19	.27	.15	.13	.09	.09	.10
6th 3 internodes									.19	.27	.16	.17	.22	.15	.11	.09	.09	.08
5th 3 internodes								.26	.20	.24	.16	.15	.24	.13	.12	.08	.09	.08
4th 3 internodes						.24	.26	.22	.20	.27	.16	.16	.19	.14	.11	.10	.09	.08
3rd 3 internodes					.25	.25	.24	.22	.19	.23	.16	.15	.21	.12	.09	.08	.09	.08
2nd 3 internodes					.23	.24	.24	.20	.18	.26	.15	.16	.22	.13	.07	.09	.09	.08
1st 3 internodes			.33	.27	.30	.30	.27	.23	.21	.26	.17	.19	.27	.15	.11	.08	.08	.10

TABLE III

TOTAL NITROGEN—% DRY MATTER

KAILUA PLOT RA

Part	1940					1941											1942			
	Jul. 27	Aug. 31	Oct. 5	Nov. 9	Dec. 14	Jan. 18	Feb. 22	Mar. 29	May 3	Jun. 7	Jul. 12	Aug. 16	Sep. 20	Oct. 24	Nov. 29	Jan. 3	Feb. 7	Mar. 14	Apr. 18
Meristem	3.10	4.14	4.00	4.14	3.48	3.38	2.76	2.56	2.24	2.18	2.61	3.11	1.92	2.42	2.30	2.46	2.58	1.58	2.26
Spindle cluster	1.17	1.29	1.32	1.22	1.12	1.08	.94	.92	.86	.81	.87	.88	.82	.95	.91	.89	.96	.84	.94
Elongating cane blades	1.51	1.36	1.34	1.30	1.31	1.27	1.13	1.04	.98	.80	.85	.89	.99	.96	1.08	.95	1.00	.88	.92
Green-leaf cane blades	1.59	1.28	1.22	1.11	1.13	1.13	.98	.92	.80	.71	.69	.72	.71	.83	.86	.80	.81	.79	.76
Elongating cane sheaths	.60	.58	.59	.54	.51	.48	.41	.34	.33	.32	.34	.34	.35	.37	.39	.38	.34	.34	.40
Green-leaf cane sheaths	.59	.42	.48	.41	.42	.41	.38	.38	.30	.31	.26	.26	.26	.28	.29	.30	.34	.29	.32
Elongating cane	2.20	1.60	1.80	1.90	1.38	1.54	1.48	1.22	1.16	1.04	1.18	1.30	.96	1.24	1.02	1.14	1.22	1.16	1.32
Green-leaf cane	1.87	.67	.47	.41	.45	.44	.56	.49	.53	.46	.24	.37	.29	.26	.26	.34	.54	.59	.70
Top internodes			.33	.19	.36	.28	.42	.45	.43	.34	.35	.28	.24	.20	.19	.22	.28	.32	.64
16th 3 internodes																			.50
15th 3 internodes																		.11	.34
14th 3 internodes																	.20	.17	.26
13th 3 internodes																.18	.17	.15	.19
12th 3 internodes															.19	.22	.17	.16	.17
11th 3 internodes													.23	.19	.18	.23	.24	.16	.16
10th 3 internodes												.27	.22	.19	.18	.24	.16	.16	.16
9th 3 internodes											.47	.27	.22	.20	.21	.21	.17	.17	.18
8th 3 internodes										.48	.37	.27	.21	.19	.18	.23	.17	.18	.18
7th 3 internodes									.44	.43	.32	.24	.21	.18	.18	.20	.16	.17	.23
6th 3 internodes							.36	.36	.33	.33	.24	.18	.16	.13	.14	.15	.14	.15	.18
5th 3 internodes							.26	.28	.23	.27	.17	.14	.11	.12	.11	.12	.12	.12	.15
4th 3 internodes					.37	.26	.23	.21	.18	.20	.13	.13	.10	.10	.09	.11	.10	.10	.12
3rd 3 internodes					.32	.22	.22	.18	.16	.18	.11	.08	.09	.09	.09	.09	.09	.11	.11
2nd 3 internodes				.35	.30	.22	.21	.19	.15	.18	.12	.10	.09	.10	.10	.09	.10	.12	.13
1st 3 internodes		.83	.43	.41	.36	.21	.29	.25	.19	.22	.17	.16	.10	.11	.11	.12	.14	.16	.17

TABLE IV

TOTAL NITROGEN—% DRY MATTER

WAIPIO PLOT RA

Part	1940					1941										1942			
	Jul 26	Aug. 30	Oct. 4	Nov. 8	Dec. 13	Jan. 17	Feb. 21	Mar. 28	May 2	Jun. 6	Jul. 12	Aug. 17	Sep. 19	Oct. 24	Nov. 28	Jan. 2	Feb. 6	Mar. 13	Apr. 17
Meristem	3.80	3.60	3.44	3.62	3.46	3.40	2.86	2.58	4.22	3.44	3.34	3.48	3.64	3.14	3.10	3.24	3.06	2.76	2.66
Spindle cluster	1.26	1.01	1.04	1.12	1.06	.99	.89	.86	1.31	.98	1.02	.97	.94	1.01	.97	.92	.85	.90	.89
Elongating cane blades	1.30	1.00	1.03	1.11	1.14	1.06	.95	.87	1.14	1.03	.96	.96	.99	1.00	1.13	.99	.86	.84	.81
Green-leaf cane blades	1.34	.87	.80	.82	.85	.81	.78	.61	.77	.80	.69	.73	.69	.74	.81	.75	.68	.66	.55
Elongating cane sheaths	.57	.44	.43	.44	.40	.42	.39	.30	.51	.42	.38	.43	.40	.38	.44	.38	.48	.35	.34
Green-leaf cane sheaths	.47	.29	.29	.30	.29	.32	.27	.24	.28	.27	.26	.25	.28	.33	.32	.33	.28	.29	.26
Elongating cane	2.16	1.40	1.32	1.30	1.34	1.58	1.28	1.30	2.14	1.56	1.36	1.44	1.58	1.30	1.52	1.28	2.00	1.40	1.44
Green-leaf cane	1.02	.32	.20	.30	.25	.30	.30	.35	.71	.39	.38	.25	.28	.35	.35	.29	.41	.33	.47
Top internodes			.11	.16	.14	.17	.19	.25	.29	.35	.29	.22	.23	.33	.34	.26	.27	.19	.29
18th 3 internodes																		.15	.20
17th 3 internodes																.25	.20	.14	.14
16th 3 internodes																.20	.16	.13	.13
15th 3 internodes														.28		.18	.15	.12	.11
14th 3 internodes														.18	.21	.19	.11	.12	.11
13th 3 internodes													.24	.18	.16	.17	.09	.12	.11
12th 3 internodes													.22	.18	.16	.15	.10	.10	.11
11th 3 internodes												.19	.20	.14	.13	.15	.11	.11	.14
10th 3 internodes											.29	.17	.21	.14	.13	.16	.11	.11	.14
9th 3 internodes											.27	.17	.18	.13	.12	.18	.12	.13	.14
8th 3 internodes										.32	.23	.13	.14	.11	.13	.15	.12	.11	.14
7th 3 internodes								.19	.23	.24	.17	.12	.11	.12	.13	.12	.11	.11	.12
6th 3 internodes							.16	.14	.16	.18	.15	.09	.10	.09	.09	.09	.10	.10	.11
5th 3 internodes						.14	.18	.13	.14	.15	.11	.09	.13	.10	.08	.09	.09	.09	.11
4th 3 internodes					.11	.14	.09	.11	.11	.12	.10	.08	.08	.07	.08	.09	.09	.09	.09
3rd 3 internodes				.12	.10	.10	.10	.09	.10	.11	.11	.07	.07	.08	.07	.08	.08	.07	.10
2nd 3 internodes				.09	.08	.10	.09	.10	.10	.11	.10	.08	.08	.07	.07	.09	.08	.08	.09
1st 3 internodes		.20	.10	.11	.10	.12	.13	.14	.13	.14	.11	.10	.08	.12	.09	.08	.10	.09	.10

TABLE V

TOTAL NITROGEN—% DRY MATTER

WAIPIO PLOT RB

Part	1940			1941										1942					
	Oct. 4	Nov. 8	Dec. 13	Jan. 17	Feb. 21	Mar. 28	May 2	Jun. 6	Jul. 11	Aug. 16	Sep. 19	Oct. 24	Nov. 28	Jan. 2	Feb. 6	Mar. 13	Apr. 17	May 22	Jun. 26
Meristem	5.04	4.00	3.76	3.74	3.08	2.98	2.86	2.57	3.02	3.94	3.48	3.24	3.66	2.58	3.26	3.00	2.68	2.44	1.76
Spindle cluster	2.02	1.24	1.09	1.09	.97	.87	.83	.75	.84	1.16	1.02	1.01	1.00	.96	1.03	.96	.91	.83	.80
Elongating cane blades	1.94	1.19	1.06	1.10	.98	.90	.88	.80	.77	1.11	1.05	1.10	1.13	1.02	.96	.90	.85	.78	.72
Green-leaf cane blades	1.87	1.33	.93	.95	.82	.71	.62	.55	.59	.77	.80	.85	.83	.77	.79	.68	.70	.59	.52
Elongating cane sheaths	.94	.60	.49	.47	.42	.34	.32	.28	.33	.56	.48	.40	.49	.40	.36	.40	.36	.32	.27
Green-leaf cane sheaths	.72	.39	.44	.34	.31	.28	.22	.21	.21	.28	.31	.32	.27	.29	.27	.30	.27	.25	.24
Elongating cane	3.98	1.66	1.66	1.74	1.40	1.24	1.12	.96	1.06	2.06	1.62	1.74	1.70	1.46	1.54	1.54	1.30	1.18	1.14
Green-leaf cane	2.12	.51	.30	.30	.28	.24	.22	.25	.23	.41	.38	.40	.37	.39	.30	.41	.34	.36	.38
Top internodes				.16	.15	.16	.14	.13	.13	.32	.33	.28	.30	.31	.21	.21	.21	.28	.34
16th 3 internodes																		.23	.25
15th 3 internodes																	.18	.18	.16
14th 3 internodes															.22	.23	.15	.16	.13
13th 3 internodes															.18	.20	.14	.13	.13
12th 3 internodes														.28	.15	.21	.13	.12	.13
11th 3 internodes														.20	.13	.14	.13	.11	.12
10th 3 internodes												.22	.20	.17	.13	.14	.12	.12	.12
9th 3 internodes											.25	.20	.16	.13	.11	.12	.12	.11	.11
8th 3 internodes											.21	.16	.13	.12	.11	.12	.11	.12	.11
7th 3 internodes									.11	.20	.15	.14	.10	.12	.10	.11	.11	.11	.10
6th 3 internodes									.11	.16	.11	.11	.09	.11	.09	.10	.10	.10	.10
5th 3 internodes								.12	.10	.13	.10	.11	.10	.10	.09	.09	.09	.09	.09
4th 3 internodes						.15	.13	.10	.09	.11	.10	.10	.09	.09	.09	.09	.08	.10	.09
3rd 3 internodes						.12	.10	.10	.09	.10	.09	.08	.08	.09	.09	.09	.08	.10	.08
2nd 3 internodes				.15	.13	.12	.10	.09	.09	.10	.09	.08	.08	.09	.09	.10	.09	.09	.09
1st 3 internodes			.20	.15	.14	.22	.12	.13	.15	.14	.10	.11	.10	.13	.10	.12	.10	.13	.11

the elongating cane blades are highest, the spindle cluster next, and finally the green-leaf cane blades. The range within each of these may be fairly considerable depending upon such factors as soil supply of nitrogen and moisture, and growth rate. The nitrogen level of the leaf sheaths also fluctuates with the levels in the blades but the nitrogen level is much lower and hence the range of variation within the sheath tissue is very narrow throughout the crop cycle. Thus, while the nitrogen level of the elongating cane blades of Plot C Kailua varies from 0.92 per cent to 1.80 per cent, the corresponding sheaths vary from 0.34 to 0.64 per cent. Although the percentage variation is about the same, the actual variation is much greater in the former.

The nitrogen content of the green-leaf cane, as might be anticipated, is between that of the elongating and the mature cane. The nitrogen content of the various internodes of the mature cane is in general highest at the top and lowest toward the base. Further, where the application of nitrogen is excessive (Tables I, II, III), the nitrogen content of the cane is high in the early months of the crops with a progressive diminution toward harvest. When the application of nitrogen is more in keeping with the requirements of the crop, the nitrogen content of the cane during the early months is much the same as later on (Tables IV and V). The larger quantities in the over-fertilized cane have the aspect of a reserve but in reality are an attribute of the maturation of cane tissues. In those plants growing under conditions of abundant moisture and nitrogen, the maturation of stem tissues does not proceed to the same degree of completion and as early as in plants grown under regulated nitrogen and moisture conditions. The likelihood of physical damage to such immature cane is very great.

In choosing among possible tissues to serve as an index to the nitrogen levels in the plant, several factors must be borne in mind: (1) It must be possible to select tissues of the same approximate morphological age; (2) the tissue selected should be easily accessible; (3) it must be possible to separate the chosen tissue from the plant with considerable precision; (4) the range of nitrogen in the chosen tissue should be as large as possible so that errors inherent in the chemical procedure are minimized; (5) the degree of correlation between the nitrogen content of the index tissue and the active portion of the plant itself should be very high; and (6) the index tissue should be as homogeneous as possible to simplify mixing and preparation of samples for analysis.

On *a priori* considerations alone, the blades of certain leaves suggest themselves as the desirable tissue. The sheaths of these leaves are not desirable because of the small range in nitrogen levels. The meristematic material, the elongating cane, the green-leaf cane are separated from the plant on arbitrary bases and cannot be collected with continuing and uniform precision. The same is true of the spindle cluster. Furthermore, preliminary statistical examination of the relation between the nitrogen levels of these tissues and the green top, the whole plant, and the growing tissues of the stem tip shows that the elongating cane blades and the green-leaf cane blades are much superior to any of the other possible tissues. In addition these can be numbered from the youngest emerging leaf downward and hence collections can be made simply and with considerable precision. Although the elongating cane blades and the green-leaf cane blades satisfy the requirements of index tissues, two points of difference occur. The elongating cane blades are always of the same order. Thus, leaves 3, 4, 5 and 6 are always present on a plant. In this respect, leaves of the same morphological age are always available. However to obtain these leaves together with their associated sheaths requires the decapitation of the plant. This is an objection, although not a serious one, since in the first place if each acre of cane were sampled only some 90 out of a total of some 27,000 plants per acre would so be sacrificed in an entire crop cycle, and in the second place, many of the decapitated plants develop a side shoot (lala) and continue to grow. On the other hand the green-leaf cane blades vary in number from collection to collection. Thus, when the plant is growing vigorously there are more leaves in this sample than toward harvest, when there may be no living leaves at all below No. 6. Further, a larger range in nitrogen is thus introduced, since in the vigorous plants there are many relatively young (physiologically) leaves characterized by a relatively high nitrogen level while in samples nearing maturity, these leaves are relatively old with a low nitrogen level. Because of this shifting in leaf activity and number, the green-leaf cane blades yield somewhat better correlations with the nitrogen of the plant itself. Whether or not such artificial improvement of the correlation is desirable cannot be stated at this time.

To obtain a complete analysis of the reliability of these two tissues, the methods of statistical linear regression were applied to each of the eight plant-crop plots (four at Waipio and four at Kailua) and to each of the six ratoon crops (three at Waipio and three at Kailua). The fourth ratoon plot was not far enough advanced to be included. In each case the regression equation expressing the relation between each of the blade samples and the nitrogen level of the entire plant, the green top only (including the leaves, sheaths, green-leaf cane, elongating cane and the meristematic material), and the growing tissues (the elongating cane, meristem and meristematic leaf basis) was determined. In Table VI are recorded the *t* values showing the significance which can be attached to the regressions. Since there was some small variation in the number of pairs of variables among individual plots, the *t* values in the columns should be compared vertically with that in mind. However, they can be compared horizontally and can be used as a measure of relative reliability. The higher the value for *t*, the more significant is the regression between the green top and the given tissue.

TABLE VI

t VALUES—GREEN TOP VS. LEAF SAMPLES

(All values highly significant)

Plot	Number of variables	*t* values	
		Elongating cane blades	Green-leaf cane blades
Kailua:			
Plot A*	15	3.44	3.24
Plot B	16	6.66	8.48
Plot C	17	3.58	5.62
Plot D	18	5.43	10.49
Plot RA	19	7.15	10.39
Plot RB	18	17.04	13.29
Plot RC	14	8.30	11.98
All Kailua Plots	117	20.90	26.05

Waipio:			
Plot A	15	4.54	3.29
Plot B	17	5.40	8.19
Plot C	18	5.74	13.09
Plot D	18	4.64	9.83
Plot RA	19	4.70	7.26
Plot RB	18	14.25	13.50
Plot RC	15	7.85	13.02
All Waipio Plots	120	18.14	28.05
All Plots	237	28.67	38.93

* Plots A, B, C, D are plant crops. Plots RA, RB, RC are ratoon crops which followed the corresponding plant crops.

Three observations may be made on the data in Table VI: (1) The *t* values for both leaf samples are of such high order that either tissue could be used to predict the nitrogen level in the green top of the plant; (2) in general the green-leaf cane blades yield higher *t* values; and (3) in general the ratoon crops yield higher significance than the plant crop. This fact is explainable on two bases, one subjective, the other objective. As the work proceeded with the plant crops, subconscious improvements and standardization of techniques of collecting and preparing samples and their subsequent analysis undoubtedly occurred. Further, the plant crops were handled in the field according to established methods, empirically applied, while the ratoon crop was handled according to the requirements of the

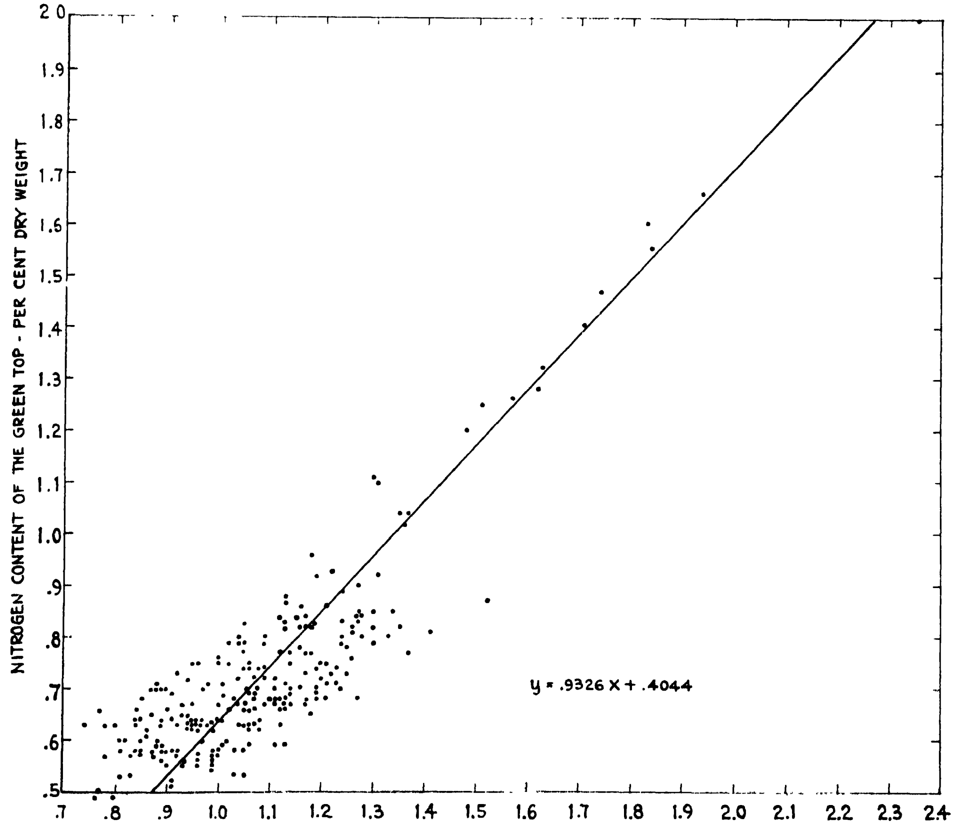

Fig. 1. Linear regression between the total nitrogen contents of the green top and elongating cane blades. Combined data of all plots.

plants. The difference in the handling of the two crops consisted of smaller fertilizer application and also fewer irrigations in the ratoon crop cycle.

The regression equation for each of the fourteen plots has been calculated, but it seems necessary to present only the equation for the combined plots. The linear regression equations for expressing the relationship between the green top and the elongating cane blades and green-leaf cane blades, are $.9326X + .4044$ and $1.1172X + .0860$, respectively. For purposes of demonstration, the data showing the relationship between the green top and the elongating cane blades are plotted in Fig. 1, revealing the high order of correlation between the two. However, were one interested in predicting the nitrogen content of the green top from the index tissue, it is apparent that a better fitting of curves could be had. The same generalization holds for the relation between the nitrogen content of the green top and that of the green-leaf cane blades. Application of the second degree polynomial resulted in the equation $y = .5354 + .01666X + .00569X^2$ for the elongating cane blades and $y = .5213 + .02349X + .00397X^2$ for the green-leaf cane blades. The latter is plotted in Fig. 2.

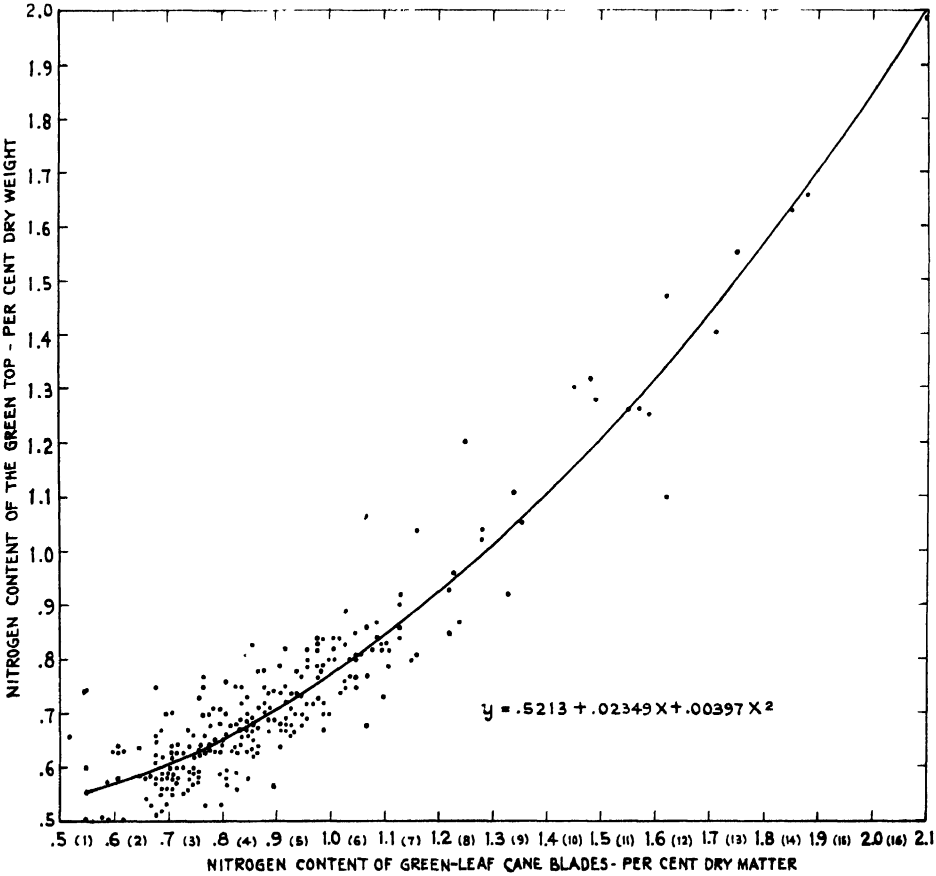

Fig. 2. Curvi-linear regression between the total nitrogen contents of the green top and the green-leaf cane blades. Combined data of all plots. (Numbers in parenthesis are code numbers used in obtaining the equation.)

WHOLE PLANT VS. BLADE SAMPLES

The nitrogen levels of the entire plant were compared with those of the elongating cane blades and the green-leaf cane blades. The *t* values of the regression coefficients are reported in Table VII.

TABLE VII

t VALUES—WHOLE PLANT VS. BLADE SAMPLES

(All values highly significant except two.
* indicates significance between 5 and 1 per cent
† indicates no significance)

Plot	*t* values	
	Elongating cane blades	Green-leaf cane blades
Kailua:		
Plot A	2.67*	1.80†
Plot B	6.16	7.05
Plot C	3.13	3.70
Plot D	4.77	7.06
Plot RA	7.64	11.36
Plot RB	11.05	15.04
Plot RC	6.00	8.96
All Kailua Plots	18.17	22.61
Waipio:		
Plot A	6.01	4.89
Plot B	6.22	11.08
Plot C	5.90	10.11
Plot D	6.20	9.01
Plot RA	3.54	9.35
Plot RB	9.23	13.94
Plot RC	5.29	9.74
All Waipio Plots	15.89	26.66
All Plots	25.02	35.67

The regression equations showing the relation between the nitrogen level of the whole plant (all plots) and the elongating cane blades and the green-leaf cane blades are $.6031X + .8091$ and $.7376X + .5638$, respectively. In Figs. 3 and 4 the data are plotted about the regression line plotted from these equations. Although the general correlations as portrayed are highly significant, the spread of the points is much greater than in Figs. 1 and 2 where only the green top was involved. Clearly the lengthening cane imposes a unidirectional drag on the relationship, and where correlations are to be made with growth the green top will be of greater usefulness.

MERISTEMATIC MATERIAL AND THE ELONGATING CANE

One further relationship should be determined before establishing the nitrogen index. Since the nitrogen level of the growing tissue, the meristematic material and the elongating cane, will have a bearing on the amount of growth made as well as the quality of growth, a good correlation should exist between that nitrogen level and that of the index. In Table VIII the *t* values for this regression are given.

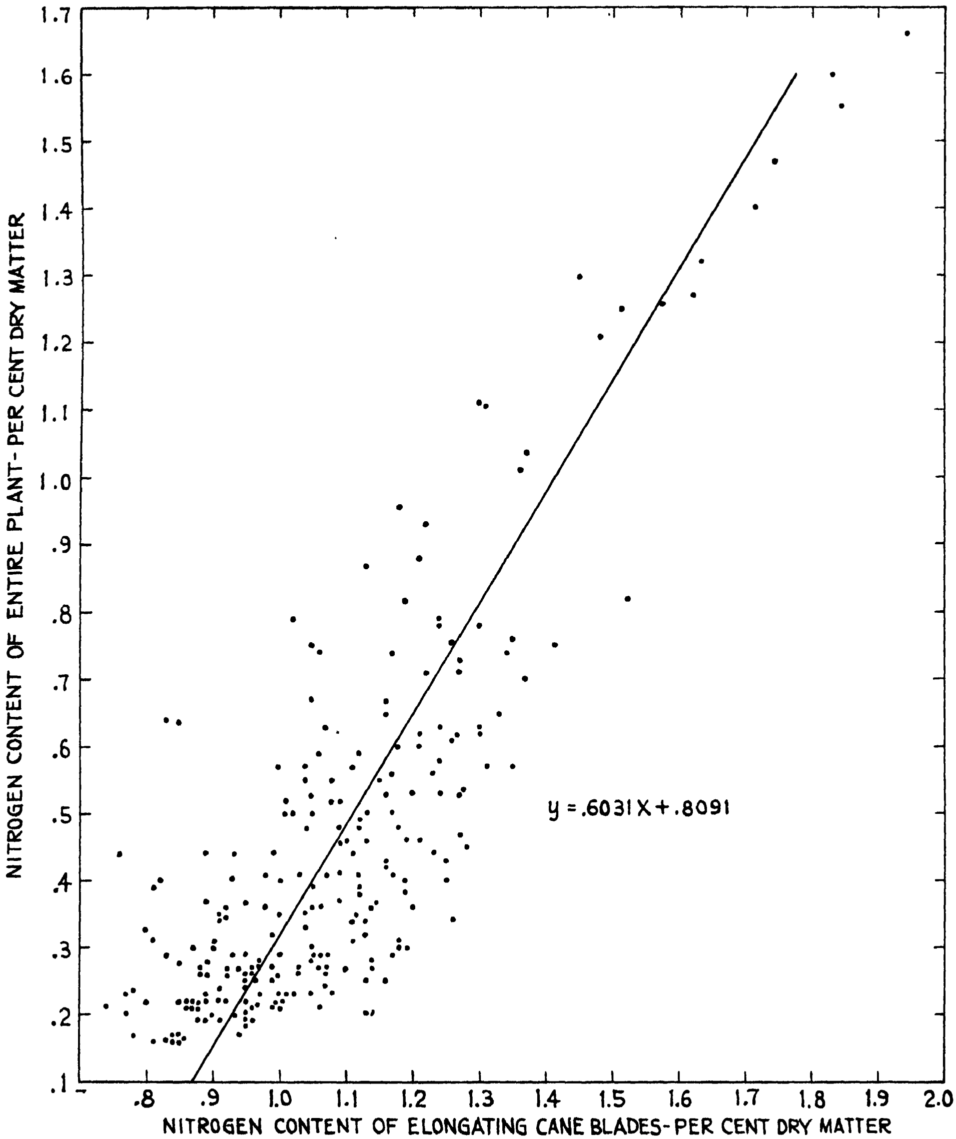

Fig. 3. Linear regression between the total nitrogen contents of the entire plant and the elongating cane blades. Combined data of all plots.

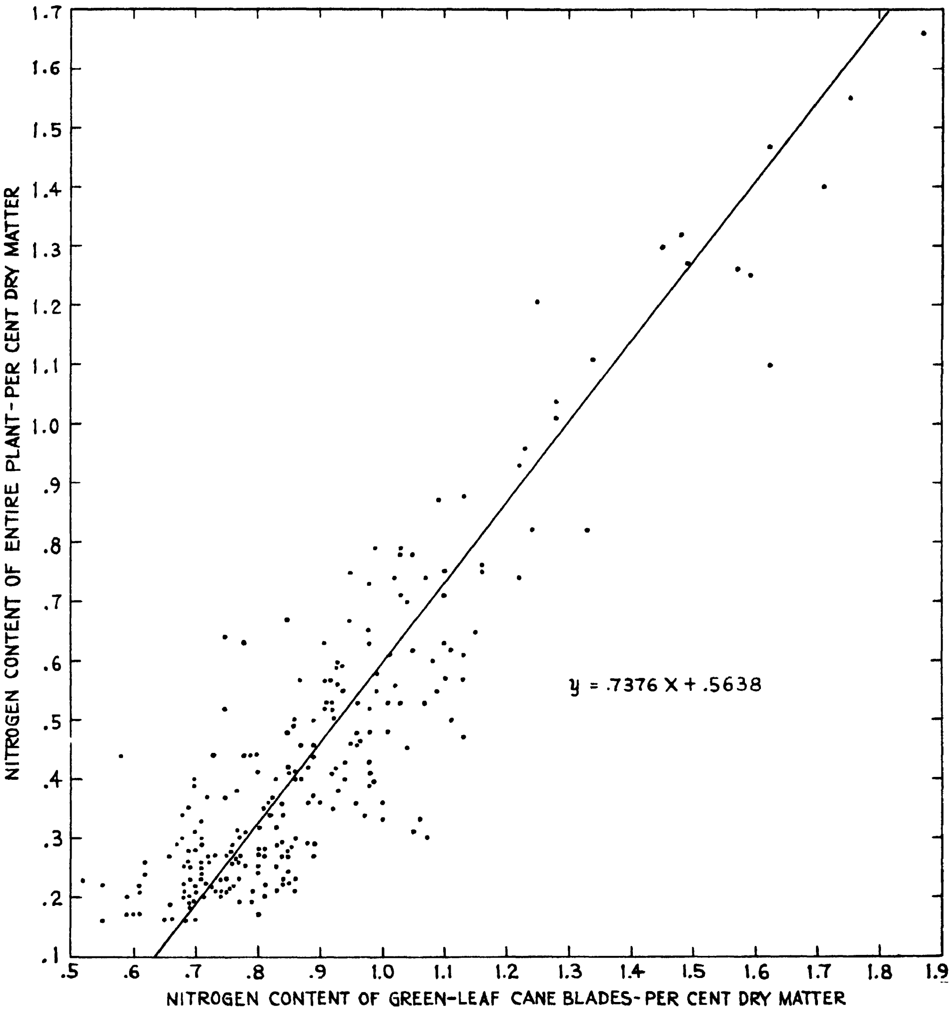

Fig. 4. Linear regression between the total nitrogen contents of the entire plant and the green-leaf cane blades. Combined data of all plots.

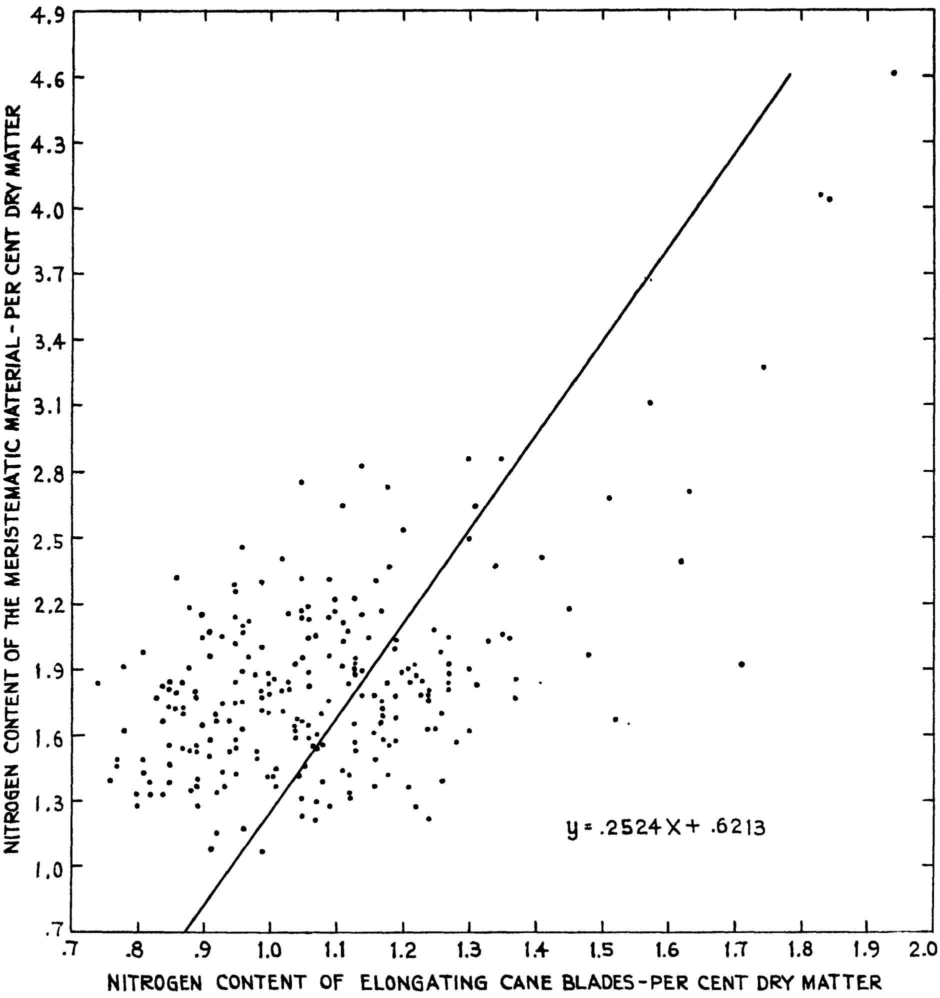

Fig. 5. Linear regression between the total nitrogen of the meristematic materials and the elongating cane blades. Combined data of all plots.

TABLE VIII

t VALUES—MERISTEMATIC TISSUES AND ELONGATING CANE VS. BLADE SAMPLES

(‡ indicates significance above 1 per cent; * between 5 and 1 per cent; no asterisk indicates lack of significance)

Plot	*t* values	
	Elongating cane blades	Green-leaf cane blades
Kailua:		
Plot A	.39	.49
Plot B	5.00‡	6.11‡
Plot C	1.56	1.71
Plot D	1.79	1.35
Plot RA	6.26‡	6.88‡
Plot RB	11.41‡	12.13‡
Plot RC	5.93‡	8.54‡
All Kailua Plots	11.91‡	13.55‡

Waipio:		
Plot A	.96	.14
Plot B	3.41‡	5.24‡
Plot C	1.64	3.53‡
Plot D	.94	1.27
Plot RA	2.45*	2.49*
Plot RB	14.60‡	7.71‡
Plot RC	7.29‡	8.89‡
All Waipio Plots	6.72‡	10.29‡
All Plots	10.96‡	12.92‡

Figs. 5 and 6 show the nature of the correlation between the two leaf-blade samples and the growing tissues, but it is clear that the spread of the points is too great to allow for accurate prediction even though a curve were to be fitted to the data. A study of the *t* values in Table VIII shows that the levels of significance are consistently higher for the ratoon crops than for the plant crops. Although these data will not permit a clear dissection of the causes of the rather

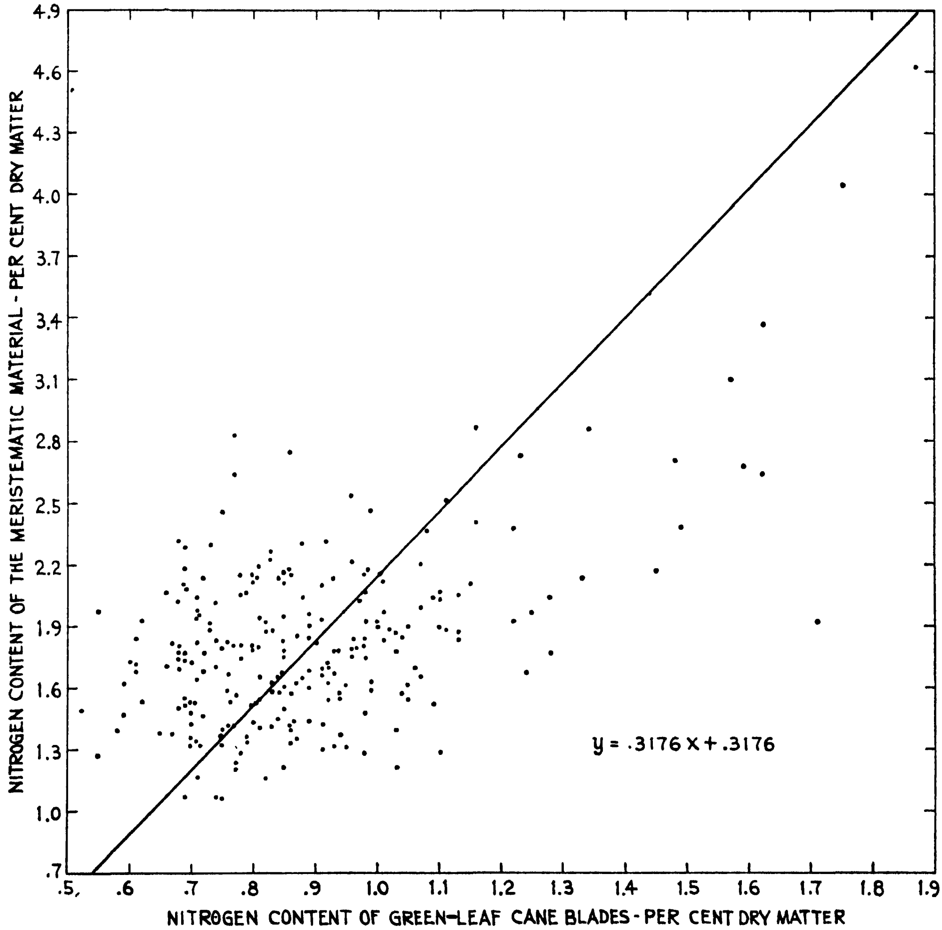

Fig. 6. Linear regression between the total nitrogen of the meristematic materials and the green-leaf cane blades. Combined data of all plots.

unsatisfactory relations between the nitrogen level of the growing point and the index tissues, it is pertinent, nevertheless, to indicate some of the possible causes.

(1) As already pointed out, the selection of the elongating cane samples and the meristematic material is arbitrary. Thus the meristematic material is the tip of stem from below the attachment of leaf No. 2 and includes about 5 inches of the meristematic and elongating leaf bases. The elongating cane is the portion of the stem between the attachment of leaf No. 6 and that of leaf No. 2. These separations were arbitrarily chosen because they did include the indicated tissues and also because in that way enough material was obtained for the necessary analyses. As time went on the collection of these samples, even though arbitrary, became more standardized and therefore there was an improvement in the correlations.

(2) The ratoon crops were fertilized with nitrogen as the plants appeared to require it. Less nitrogen was used in all cases than in the plant crops. It may follow from this that plants which are receiving nitrogen in relation to their needs will distribute it more precisely than those which have excessive amounts available.

(3) Hoagland *et al* (4, 5) and Steward *et al* (10) have shown that the accumulation of salts by a cell is in part determined by its respiration rate, *i.e.*, the more active a cell is metabolically, the greater will be the accumulation of salts, other things being equal. If growth rates can be used as an index of metabolic activity, it seems that the Kailua meristems are at a lower level of metabolism than those at Waipio and that the cause of the poorer correlations, when the data of the two places are combined, may be related to that fact. Thus for example the *error of estimate* for the relation between the green-leaf cane blades and the green top at Kailua is .0938; that at Waipio, .0805, and when the two populations are combined, the error of estimate is .0900. The *error of estimate* for the relation between the growing tissue at Kailua is .1527, at Waipio, .1642, but when the two are combined, it is .1878. Here the error of the combined plots is considerably increased indicating in this case that the Kailua and Waipio populations do not overlap each other as in the other comparisons and that another factor attributable to the locale has been introduced, but one which does not affect the correlations of other parts.

One other problem needs to be examined before ending this portion of the paper. Yuen and Hance (15) in collecting leaf material for nitrogen determinations have adopted the very simple procedure of using an ordinary paper punch and collecting disks of leaf-blade tissues. Because of its simplicity it may be desirable to use that method if it can be shown that it yields reliable correlations. To test this point, on April 8, 1942 a special collection of cane plants (32–8560) of several different ages was made, and separated into parts as above. In addition leaf punches were taken from the elongating cane blade and green-leaf cane blade samples, respectively. The relation between the nitrogen levels of the green top of the plant and those of the two blade samples as well as those of the leaf punches are shown in Table IX.

TABLE IX

t VALUES—GREEN TOP VS. BLADE AND LEAF-PUNCH SAMPLES

(All values highly significant)

Tissue	Green top
Elongating Cane:	
Whole Leaf Blades	12.15
Leaf Punch	9.44
Green-leaf Cane:	
Whole Leaf Blades	7.50
Leaf Punch	7.38

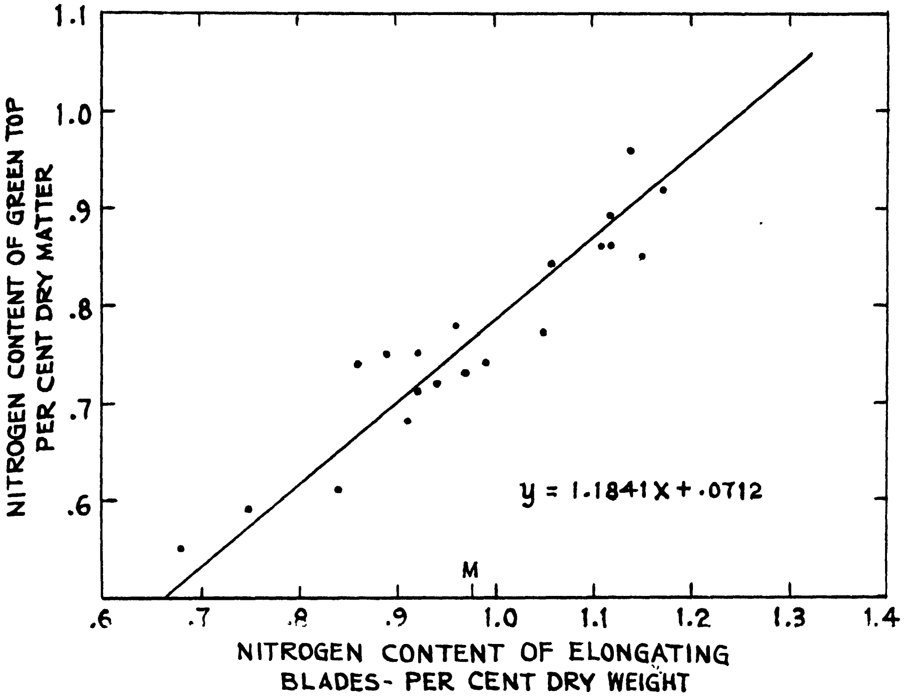

Fig. 7. Linear regression between the total nitrogen of the green top and the elongating cane blades (32-8560).

In Figs. 7 and 8 are plotted the data about the regression lines showing the relation between the green top and elongating cane blades and the leaf punches of these blades, respectively. Judging from the *t* values in Table IX and the excellent fit of the data to the lines in Figs. 7 and 8, it seems quite clear that although the leaf punches are not quite so good as the whole leaves, they are wholly satisfactory and can be used with a great deal of confidence.

CONCLUSION OF PART I

Because of the high *t* values obtained for both the elongating cane blades and the green-leaf cane blades, it is apparent that either tissue can be adopted as an index to the nitrogen levels of the whole plant and the green top. However, in many cases the green-leaf cane blades are somewhat superior to the other blade samples. That this may be the result of an artifact is possible. The very same

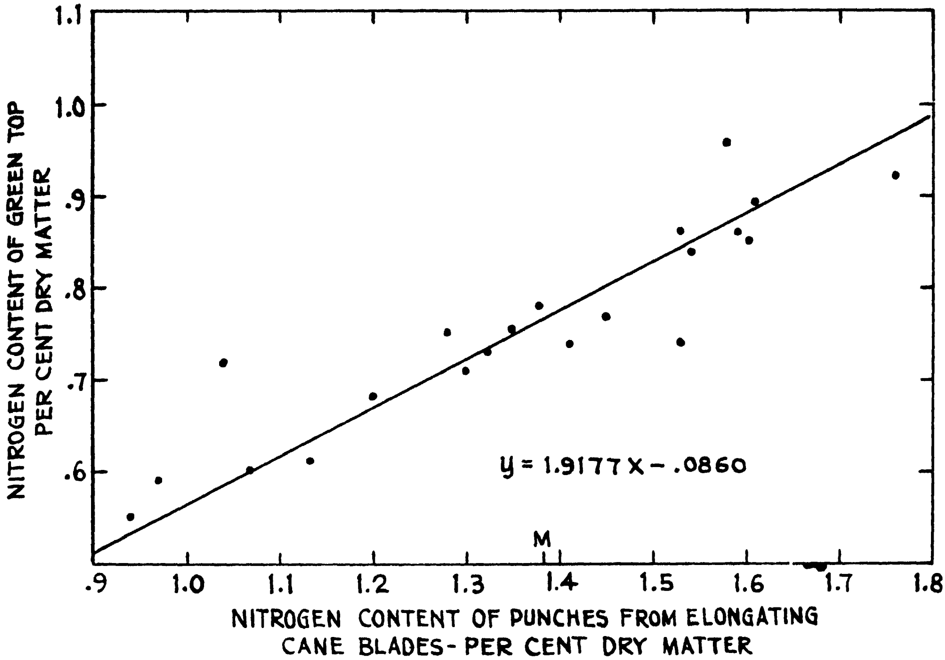

Fig. 8. Linear regression between the nitrogen content of the green top and punches of green tissue taken from the elongating cane blades of Fig. 7 (32–8560).

number of leaves of the elongating cane blades is taken each time while the number of the older leaves varies from season to season. In effect this variable was eliminated in compiling the data of Table IX in which case the *t* values were better for the elongating cane blades.

It is necessary, however, before making the final selection of an index tissue to wait until similar statistical studies can be made with reference to phosphorus and potash. It will be remembered that the sheaths of the elongating cane leaves were superior to those of the green-leaf cane blades as indices of the moisture level (3). But whether the one tissue or the other is used, a high order of confidence can be had in the value of the results.

The meristematic and elongating tissues of stems and leaves of the ratoon crops, *i.e.*, those crops controlled according to the levels indicated by the leaf blades, show good correlations. It appears, however, that the nitrogen level of these growing tissues is influenced by local influences other than the nitrogen levels of the plant, and hence must be studied further in that light.

Part II

QUANTITIES OF NITROGEN CONTAINED WITHIN A CROP THROUGH ITS CYCLE

In conducting the field studies rather complete growth measurements were taken from the time the crop was 1 to 2 months old until it was harvested. These measurements included rates of elongation, leaf emergence, leaf drop and, finally, the circumference of the various internodes. These measurements were made on twenty pilot plants in each plot and, of course, the same pilot

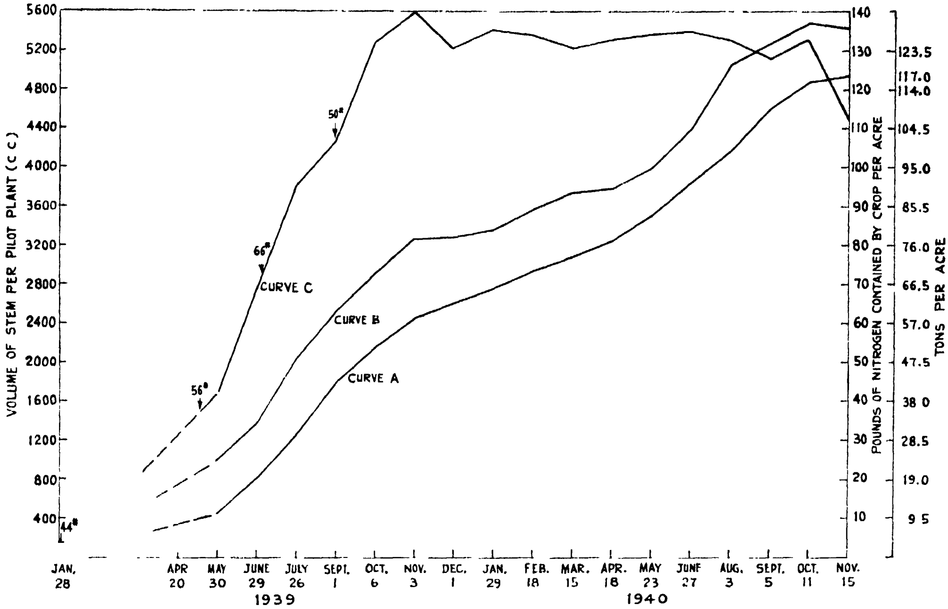

Fig. 9. Growth and nitrogen record for Waipio Plot C. Curve A when read off the left-hand axis represents the accumulating volume of stem per pilot plant. When read off the outside right-hand axis, it represents the accumulating tonnage of millable cane per acre. Curve B represents the total tonnage per acre of millable cane and green portions and is read off the outside right-hand axis. Curve C represents the pounds of nitrogen per acre contained within the above-ground parts of the plants and is read off the inside right-hand axis. Arrows on Curve C represent time of nitrogen applications in amounts indicated per acre.

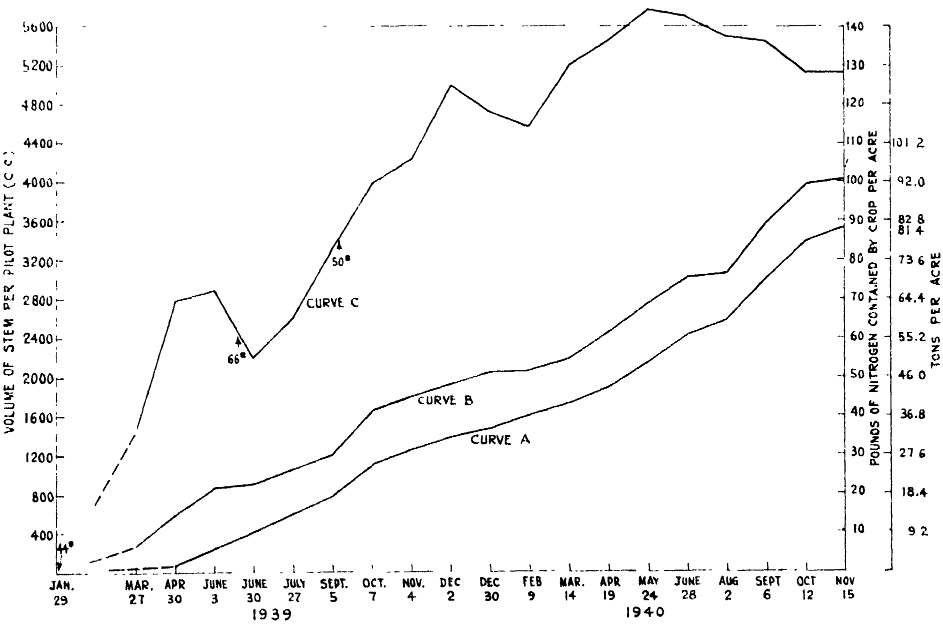

Fig. 10. Growth and nitrogen record for Kailua Plot C. (See legend to Fig. 9 for meaning of curves.)

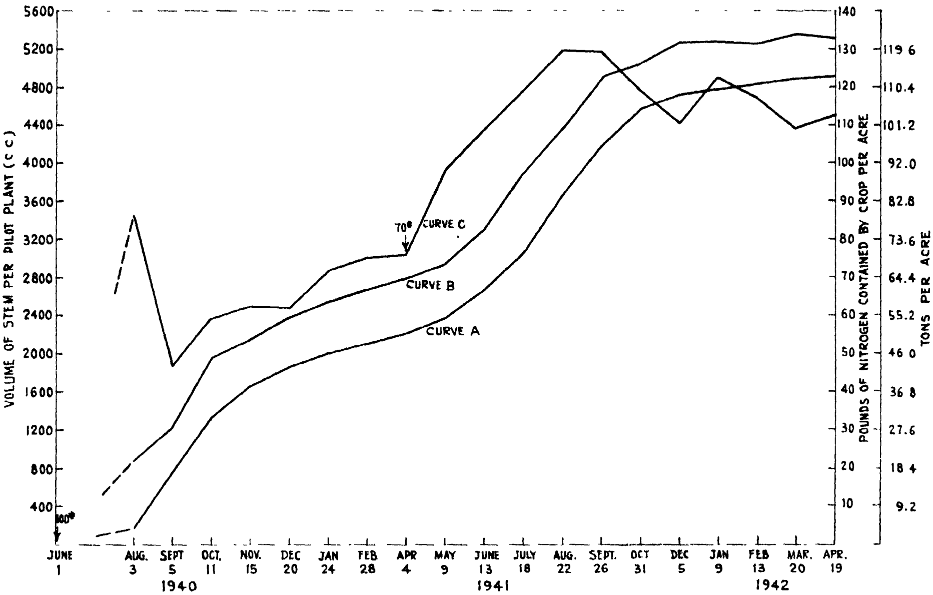

Fig. 11. Growth and nitrogen record for Waipio Plot RA. (See legend to Fig. 9 for meaning of curves.)

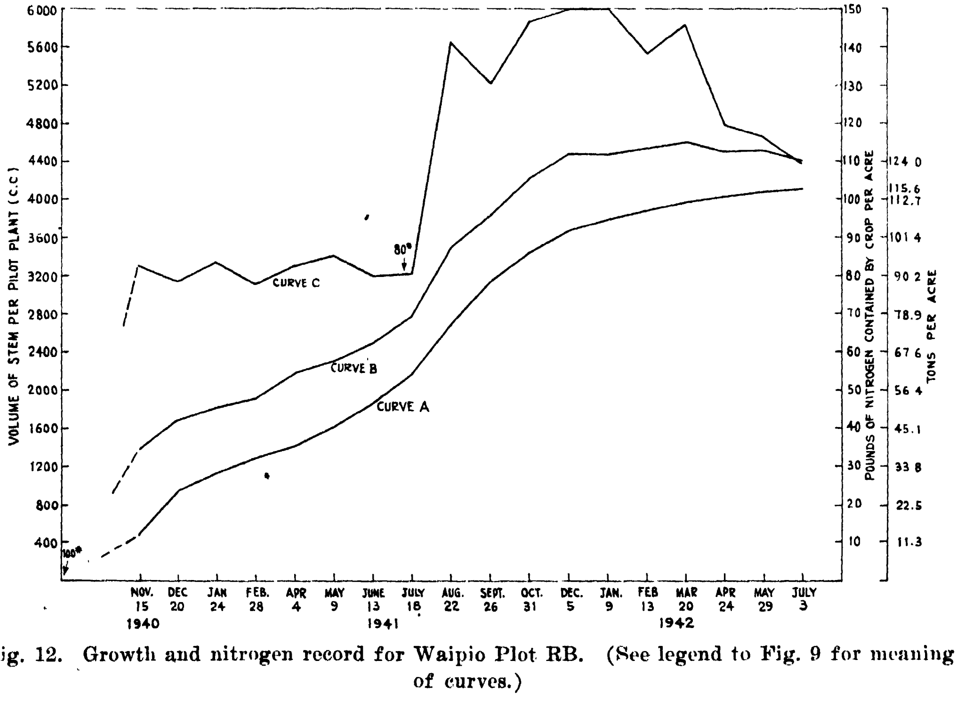

Fig. 12. Growth and nitrogen record for Waipio Plot RB. (See legend to Fig. 9 for meaning of curves.)

plants were used throughout the cycle. Occasionally a pilot plant is destroyed either by rats or breakage and has to be abandoned. Also, throughout the crop cycle field samples of whole plants were taken and analyzed for nitrogen, etc. At the end of the cycle the crop is harvested and weighed. These three measurements make it possible to calculate the tonnage of cane per acre at any one time in the crop cycle and also the amount of nitrogen in the crop at any one time. Composite graphs are shown in Figs. 9, 10, 11 and 12, and represent Plots C, Waipio and Kailua (9 and 10), two plant crops which were handled according to ordinary empirical plantation practice and Plots RA, RB, Waipio (11 and 12) ratoon crops subjected to controlled management. Unfortunately the ratoon crops at Kailua were so badly damaged by rats that the growth records are not reliable and hence are not included. The methods followed in the construction of these graphs will be described fully for Fig. 9, so that certain relatively minor reservations may be made relative to the reliability of the curves. To begin with, Curve A (Fig. 9) is plotted and represents the volume of the cane stem (average of the twenty plants) accumulating month by month until the crop is harvested. The cane included the green-leaf cane and all of the dry-leaf cane. It is reasonable to expect that the whole crop was growing at the rate indicated by Curve A. Now, at the end of the crop it was harvested and the yield of cane was 117 tons per acre. On the right-hand side of the graph, 117 is written at the end of Curve A, and the vertical axis is equally divided down to zero, accordingly. Now by projecting across to Curve A it is possible to obtain an estimate of the cane tonnage on the field month by month. But the green leaves and meristem contain much nitrogen and hence they must be included in the calculations of the total tonnage of both millable cane and green tissue. At this point the data obtained from the monthly collections are used. Each collection was made up of whole plants taken apart and weighed. From these data a ratio between the cane and the green tissues not included in the mill cane is obtained. Reading the tonnage on Curve A from the right-hand vertical axis and using the ratio of whole plant to millable cane, a value is obtained which when plotted for the crop cycle is Curve B. Curve B represents the total tonnage (cane and green top) per acre and, of course, is read off the right-hand vertical axis. Variations in the space between A and B represent variations in the amounts of green top tissues held by the crop. Knowing the nitrogen composition of the crop, month by month, it is a simple matter to calculate the amount of nitrogen in pounds per acre contained within the crop month by month. When the results of this calculation are plotted against pounds of nitrogen per acre Curve C is obtained. Arrows on Curve C represent the time applications of nitrogen were made to the field in the amount indicated per acre.

There are certain reservations which should be noted. Early in the crop there are many shoots which later are killed out in competition. Since Curves B and C are based on those shoots which make up the completed crops, they are lower than they should be during the first two to five months. Also, the exact nature of the curve during the very early months is not known and is simply drawn from the first determined point toward zero. Curve C must be fully understood, otherwise erroneous conclusions may be drawn. It simply represents an estimate of the amount of nitrogen in the crop at any one time. It does not mean necessarily that this is the total amount of nitrogen needed by the crop. Thus, the nitrogen of the root system and that in the fallen leaves is not included. Just how much may be contained in these tissues is difficult to calculate since the nitrogen content of these tissues will vary considerably. When the roots are young and growing rapidly they will contain much more nitrogen than they will toward harvest. The quantity of nitrogen contained by the roots at harvest will depend upon the degree of senescence attained because of temperature, drying out, or because of the level of soil nitrogen. The roots of a well-matured crop possess relatively small numbers of active root tips and may therefore contain only small amounts of nitrogen. In the early growth, however, the roots are active and must contain considerable quantities. As the crop ages and the roots decline in activity, they probably give up much of their nitrogen to the top.

Something of the same type of processes are involved in dying leaves. It appears that a dead leaf, still attached to the plant, contains about one third to one half the nitrogen which it contained when fully active. How much of the nitrogen so lost moved into the plant and how much was leached from the leaf is not known. Both processes undoubtedly take place. Once the leaf has fallen, it decays. The soluble nitrogen as well as other solutes will be leached out by rain or by irrigation water and find their way back to the soil to be reabsorbed by the growing plant. Other processes would involve bacterial and fungal decomposition. How long before the nitrogen so taken remains in the bodies of the saprophytes would depend on a multitude of factors. But, no matter what the disposition of the nitrogen in the roots and "trash", varying amounts depending on many factors will not find their way back into the above-ground plants.

Nor does the amount of nitrogen indicated by Curve C show that that amount is the minimum amount needed. Thus, Fig. 9 shows 140 pounds contained within the crop which eventually yielded 117 tons of cane. But Fig. 10 reveals 144 pounds contained within the Kailua crop which ultimately yielded 81 tons of cane. To repeat, Curve C simply represents the amount of nitrogen contained by the particular crop whether necessary or not. Its usefulness consists in indicating the disposition of nitrogen through the crop cycle, and studies of such curves and experiments with them may ultimately aid in bringing the applications of nitrogen nearer to the actual needs of the plant.

Plot C—Waipio (Fig. 9):

The total amount of nitrogen added to this plot was 216 pounds applied as indicated. There was a very rapid absorption of it by the plant until November 3 when the maximum amount contained reached 140 pounds per acre. After this the nitrogen content remained more or less uniform until just before harvest when it dropped to 112 pounds of nitrogen contained in 117 tons of cane. In other words in the harvested crop there was about one pound of nitrogen per ton of cane. It should not be assumed that there was no further absorption of nitrogen after November 3. Even though the amount in the crop did not vary, actually as the leaves die and drop off they carry some nitrogen with them, but at least it seems that no more nitrogen is absorbed than is lost. It is also clear that as the plant grows it is using the nitrogen which is being released by the maturing tissues. (cf. Table II, note declining nitrogen percentage of the various internodes.) One final observation can be made. Of the 216 pounds of nitrogen applied to the field, a maximum of 140 pounds was contained in the crop at any one time.

Plot C—Kailua (Fig. 10):

The total amount of nitrogen applied to this plot was 160 pounds. There was rapid absorption until May 24, 1940, but two periods of drought resulted in temporary losses. Drought causes a reduction in leaf area as indicated by the narrowing of the space between Curves A and B as well as a lower nitrogen level in the remaining leaves. At the peak the crop contained about 144 pounds of nitrogen and, as it approached harvest, it lost nitrogen until 128 pounds remained. Here we have a ratio of 128 pounds of nitrogen to 81 tons of cane, or about 1.6 pounds of nitrogen per ton of cane. Thus with a much smaller yield of cane, about as much nitrogen was consumed as at Waipio Plot C. Reference should be made to Table I, inspection of which will reveal the high levels of nitrogen remaining in the cane. Clearly the nitrogen added was excessive. Table III shows that at Kailua, reducing the amount of nitrogen to 100 pounds resulted in considerably reduced cane levels.

Were it possible to add the nitrogen fertilizer "just right," it should not be impossible to reduce the difference between that added and contained in the parts above ground, even though it would never be possible to exactly balance them. Waipio Plot C contained one pound of nitrogen per ton of harvested cane. Waipio Plot D contained 115 pounds of nitrogen at harvest and yielded 114 tons of cane, but at Kailua Plot C, 1.6 pounds of nitrogen were contained per ton of harvested crop. It would appear that at least a major part of the additional 0.6 pound was excessive.

Now by controlling the crop it should be possible to minimize the difference between the nitrogen added and the nitrogen needed by the crop, although forthcoming studies may reveal that reducing the nitrogen to the minimum may result in increased absorption of potash and therefore perhaps a false economy (2). But ignoring this possible factor for the present, Plots RA and RB at Waipio are cases in point. Plot RA (Fig. 11) was ratooned June 1, 1940, at which time 100 pounds of nitrogen were applied. There was a rapid growth and absorption up to August 3, at which time about 86 pounds were accounted for. As the crop closed in, and the older leaves died, the total amount of nitrogen dropped to 50 pounds. From this time on even though the growth was rapid, there was a slow accumulation up to 75 pounds on April 4. At this time the leaf tissues showed a drop in nitrogen and it became apparent that an application of nitrogen was necessary. The amount to be added was determined by striking a proportion between the light already experienced by the crop to the 100 pounds of nitrogen added as against the probable light to which the crop would be exposed until harvest. The answer was 70 pounds, which was then applied. Following April 4 there was a rapid absorption again from 75 pounds on April 4 to 130 pounds on August 22. Ignoring the residual nitrogen, of the 70 pounds added 55 pounds were recovered by the tops alone. Of the 170 pounds added, the crop at its maximum contained 130 pounds or about 76 per cent. At harvest the 113 tons of cane (15.2 tons of sugar) contained 112.5 pounds of nitrogen! Is this repeated ratio of one pound of nitrogen per ton of cane an accident? If it is not, it may constitute a valuable check for fertilizer programs. Of the original 100 pounds (Fig. 8), only 75 pounds were in the crop on April 4. Just how much was contained in the dead leaves and roots is not known, but that and the 75 pounds represent the recovery of the 100 pounds. It is possible that had a smaller application been made at the start, there would have been greater recovery. The second application increased absorption to 130 pounds following which there was a decline even though growth was still very active. Now, since the application of the second quantity of nitrogen was calculated on the basis of the original 100 pounds, it follows that if that was too high, the second application would also be somewhat higher than necessary.

Waipio Plot RB (Fig 12) was handled in a somewhat similar fashion. It was started August 28, 1940, at which time 100 pounds of nitrogen were added. Growth was very rapid until checked by winter temperatures, but during that period about 80 pounds were held by the above-ground parts of the plant and appeared to be sufficient for the growth of the crop until some time in May 1941, when the leaf nitrogen began to drop off rapidly (cf. Table V—Elongating cane blades). This starvation period was deliberately prolonged as a hardening period until July 11 at which time the leaf nitrogen was very low. (Incidentally, through this period of hardening, full irrigation had been maintained.) On July 13 the calculated amount of nitrogen was determined to be 80 pounds which was then applied. The absorption of the new addition was apparently instantaneous, for by the next sampling the nitrogen level rose to 140 pounds and the response in growth was also rapid. It is interesting to observe (Table V) that the rise of nitrogen levels is noted almost solely for the top of the plant with the mature, old cane getting little or none of the fertilizer applied.

The maximum quantity of nitrogen contained by the tops reached 152.9 pounds (December 5, 1941), about 85 per cent of the 180 pounds, and remained at high levels until the crop was being prepared for harvest. A rapid decline in the amount of green tops caused the reduction in the amount of nitrogen to 109 pounds at harvest (115.6 tons of cane per acre and 16.26 tons of sugar).

At Waipio Plot C of the 216 pounds applied, 140 pounds were found in the crop, or 65 per cent of the total. In Waipio Plot RA of the 170 pounds applied, 130 pounds or 76 per cent of the total was found in the crop. At Waipio Plot RB of the 180 pounds applied, the crop contained 152.9 pounds or about 85 per cent. To be sure, these calculations ignore residual nitrogen. But in the second and third plots, more sugar was obtained than from Plot C with fewer pounds of nitrogen added. Here, not only is there a saving on the fertilizer and its application, but there is an improvement in yield of sugar. How much this procedure can be refined and how far the amount of nitrogen can be reduced will depend upon more work, but these data indicate the possibilities.

CONCLUSIONS FOR PART II

Figs. 9-12 reveal many points of interest. In Fig. 9 Curve C shows the absorption of nitrogen resulting from empirical applications of nitrogen fertilizers. Judging from the steepness of the curve while applications were being made, there was no apparent need to make each additional application at the time it was made, and apparently the final application could have been saved. Fig. 10 Curve C shows the same situation for the Kailua crop. Here, however, following the initial addition of 44 pounds, there was a recovery of 72 pounds, indicating quantities of residual nitrogen were being absorbed. But the most striking part of this figure is that the crop which yielded 81 tons of cane contained more nitrogen than the much larger crop at Waipio. If an attempt is made to mature such a crop during periods of high temperatures and abundant rainfall, quality is certain to be poor. In this case the quality ratio was nearly 12. On the other hand, such a crop, if it is to be harvested during periods of drought and low temperature may yield satisfactory quality. In contrast to these two crops are those shown in Figs. 11 and 12. In these the nitrogen was applied more as the crop seemed to require it, resulting in a definite change in the slope of the curve following the addition. Furthermore, the apparent recovery of applied nitrogen was better in each case than where the nitrogen was applied empirically. Another point of interest is the speed of absorption of the second application shown in Figs. 11 and 12. Fig. 12 shows a tremendous rise in the nitrogen within the one collection period. The crop had exhausted the soil nitrogen and when the application was made in the middle of July the soil was warm and moist. Absorption under such conditions is excellent. Fig. 11 shows the second absorption to be much slower. The ascent of the curve extends over several sampling periods. Very probably the more important limiting factors here were the lower soil temperature and lesser root activity early in April.

Finally, one might add after viewing these cases, how different each one is, and how essential that applications both in quantity and time be made as the crops indicate the need for them.

Summary

1. Fourteen plots of sugar cane were grown under field conditions at Waipio and Kailua including four plots of plant cane at each place and three of ratoon cane.

2. Plants from each of the plots were collected at approximately monthly intervals, separated into their various parts and analyzed for total nitrogen.

3. The data so accumulated are subjected to statistical treatment to obtain the most reliable nitrogen index tissue.

4. The elongating cane blades and the green-leaf cane blades are both wholly satisfactory as indices. The same may be said of leaf punches taken from these leaves.

5. The amounts of nitrogen contained within each of four crops are calculated and discussed in relation to the amounts of nitrogen fertilizer applied.

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A Search for Guidance in the Nitrogen Fertilization of the Sugar Cane Crop

Part I—The Plant Crop

By R. J. Borden

Measurements and analyses made on samples from sugar cane crops which had been differentially fertilized with nitrogen have pointed out a number of effects from the nitrogen treatments upon the yields and the composition of the crop. These may be summed up as follows: to a plant crop of 32–8560 cane which had already been given 100 pounds of nitrogen per acre, an additional 60 pounds applied in June when the crop was 10½ months old had the following effects at the final harvest 10 months later: (a) *definitely increased* (1) *the percentage of nitrogen in the total dry weight, in the leaf-punch samples, and in the crusher juice,* (2) *the percentage of chlorophyll in the green-leaf blades,* (3) *the tons per acre of reducing sugars, and* (4) *the pounds of nitrogen per acre in the dry weight;* (b) *possibly increased* (1) *the total green and dry weights,* (2) *the percentages of tops and of moisture in green weight,* (3) *the percentage of reducing sugars,* (4) *the total tons of sucrose and of total sugars, and* (5) *the tons of millable cane and of commercially recoverable sugar;* (c) *decreased the percentage of phosphate in the total dry weight;* (d) *possibly decreased the percentages of sucrose and of total sugars; and* (e) *had no effect on the yield per cent cane.*

To a comparable crop which had received 160 pounds of nitrogen, an additional 60 pounds applied in June at 10½ months had these effects on the crop harvested at 20½ months: (a) *definitely increased* (1) *the percentage of nitrogen in the total dry weight and in the crusher juice,* (2) *the percentage and the tonnage of reducing sugars;* (b) *possibly increased* (1) *the percentage of nitrogen in the leaf-punch samples,* (2) *the pounds of nitrogen in the total dry weights, and* (3) *the percentage of sucrose and of total sugars;* (c) *possibly decreased the yield per cent cane and the commercial sugar yield; and* (d) *probably had no effect on* (1) *the total green and dry weight, or the yield of millable cane,* (2) *the per cent tops and moisture,* (3) *the chlorophyll in the leaf blades,* (4) *the percentages of* P_2O_5 *and* K_2O *in the total dry weight, or* (5) *the tonnages of sucrose and of total sugars.*

The many data have been studied for their relationships, and specific values have been recorded for further affirmation or denial. Chief interest centers in the fact that the differences in the nitrogen treatments were quickly identified by the changes in the percentages of nitrogen as found in either samples of the total dry weight, of the leaf-punch samples, of the leaf blades, or of the crusher juices. Thus any one of these analyses was shown to reflect the nitrogen supply which had been available up to the time of sampling. The specific percentage figures which were associated with the crop at 10½ months will be watched further to determine whether they can indicate an adequacy or an inadequacy in nitrogen concentration to support optimum yields for another 10 or 12 months of the growth period.

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INTRODUCTION

Probably no plant food which is made available to sugar cane crops through commercial fertilizers has received and deserved more consideration than nitrogen. Sugar plantation men everywhere recognize the value and the need for nitrogen and are quick to recognize its deficiency in the field through leaf symptoms. If these nitrogen deficiency symptoms are identified early enough in the crop's development, it is an easy matter to correct them quickly by making an application of a soluble nitrogen fertilizer, but if the crop has lodged, then an economic correction is more difficult and often impractical.

To use nitrogen fertilizer efficiently, one must recognize how exacting the cane plant is with respect to this nutrient: too little produces too little growth whereas too much means the wrong kind of growth. In a dry soil it remains unavailable until moisture comes, while in a water-logged soil the sluggish root system cannot pick it up. Under certain soil conditions it can be leached beyond the root zone. Weeds will compete for it. Used where organic materials with high carbon-nitrogen ratios have gone into the soil, it is pounced upon by the soil organisms, and its release from this microorganic complex, which is probably never complete, may come at the wrong time—too late.

Sugar cane grown continuously on the same areas without periods of fallow is almost invariably fertilized with nitrogen. Present-day field practices have evolved largely from years of experimental work and the careful observations and experience of good cane farmers; a contributing factor has undoubtedly been the results from local research investigations. This research continues for there are still many moot points involved in finding that procedure for nitrogen fertilization of the sugar cane crop which will produce the maximum sugar yield from a minimum of cane stalks harvested. Thus the present study is another effort to obtain information that will lead to better nitrogen fertilization for the sugar cane crop.

THE PROBLEM, PLAN, AND PROCEDURE

1. *The Problem:*

In common with many other investigators of soil and plant relationships, we are especially desirous of finding some index of plant or soil or both which can be used to guide our nitrogen fertilization. Former soil studies alone have not given us as satisfactory an answer for nitrogen needs as they have indicated for phosphate and potash, and some of us now lean more toward plant studies, following the suggestions of those scientists who have made their plants tell them whether or not there is a need for more nitrogen.

A sugar cane crop which is harvested at 22-24 months is made up of a somewhat complex group of stalks which started to grow almost anytime within the first 16 to 18 months, and the stalk-age composition of every crop will vary. Thus although those stalks which get their start during the first couple of months usually make up the larger part of the crop at harvest, this condition can actually vary considerably. Cornelison (2) has recorded a case in which 35 per cent of the H 109 stalks found at harvest had not started their growth until after the stalk census was made at 4 months. In another instance Cornelison (3) states: "At 24 months, POJ 2878... the entire stand was secondary growth".

Because of the growth habits of our best cane varieties, the stalks are usually recumbent some 10 to 12 months before they are harvested, and after this recumbency it is difficult and often impractical to apply more nitrogen fertilizer which might be needed to correct a late-identified deficiency, unless it can be distributed through the irrigation water. Furthermore, if this late application of nitrogen is a large one or makes the total amount applied excessive, and is followed by subnormal sunshine or a relatively short period of active growing time before harvest, then there is the likelihood that it will not be completely assimilated and that a poor cane quality and sugar recovery will be the result. Thus it is essential that when an adjustment of a partially completed nitrogen fertilizer practice is needed, it must be made during the early part of the growth period while it is still physically possible to make another fertilizer application.

More specifically our actual problem then is somewhat like this: On the basis of past experience, skilled sugar cane planters can usually guess within 50 or 75 pounds of the optimum amount of nitrogen that a specific crop of their cane will need. But it is this guess which can make a difference between a profit and a loss for the planter. Guidance to make this guess less uncertain will need to be at hand some 8 or 12 months before the crop is to be harvested, and at this time the crop will already have been given a basic application of perhaps 75 to 125 pounds of nitrogen per acre, and will be well established and perhaps "covered in". It then becomes necessary to decide whether another 50 to 75 pounds or more will be needed, so that we can get this applied before the cane "goes down". If we apply too little at this time, we may limit the final cane yield and come out with a lower sugar yield than we might have had if the cane crop had been larger; if we apply too much at this specific time, then we stand the chance of producing a lot of extra cane tonnage from which the sugar recovery will be made at a monetary loss. In either instance we must gamble on the weather conditions of the subsequent 10-12 months which will influence the completeness with which this additional amount of nitrogen will be assimilated before harvest time comes.

Furthermore it is somewhat doubtful if we can disregard the contribution of nitrogen which the soil itself can continue to make to the cane crop during the second half of its relatively long growth period, and this contribution can complicate our interpretation of the subsequent nitrogen needs of the current crop which are based on plant analyses alone that were made earlier.

From the foregoing it is apparent that our search for a nitrogen index from the cane crop itself, before the crop "goes down", is a worthy one, but one that is fraught with interactions.

Since there has been considerable interest shown in foliar diagnosis of plant deficiency symptoms, and as a local technique of leaf-punch sampling for nitrogen analyses seemed to offer promise of having the cane crop reveal its nitrogen requirements concurrently with its development, it seemed advisable to study the results from leaf-punch nitrogen analyses made from active cane leaf samples taken periodically throughout the growing period of crops which had been similarly fertilized with nitrogen in their earlier months and subsequently given differential nitrogen treatments; all with the hope that the leaf-punch nitrogen index would be found to supply the guide to optimum sugar yields from controlled nitrogen fertilizations. Concurrently an opinion was expressed that knowledge of the total nitrogen in samples of the entire crop, and perhaps of total nitrogen in the crusher juices might be what we were looking for; and in order to learn how differentials in nitrogen fertilization can affect the development and composition of the crop at various ages, current sugar analyses were very desirable contributions.

2. *The Plan:*

Following conferences between staff members who were to have a part in the investigation, a Grade A field experiment (Waipio No. 108 ATN), from which cane samples could be taken periodically for specific analyses, was proposed for installation in Waipio Field L. A simple plan was agreed upon wherein there would be (*a*) three levels of nitrogen fertilization, and (*b*) one difference in the time of making the last application for one of these total amounts which were prescribed. The specific plan of fertilization was then set up as follows:

	Appl. No. 1 7/26/40	Appl. No. 2 9/16/40		Appl. No. 3 11/15/40	Appl. No. 4 3/17/41	Appl. No. 5 6/23/41	Total per acre		
Plot identity	Lbs. P_2O_5	Lbs. N	Lbs. K_2O	Lbs. N	Lbs. N	Lbs. N	Lbs. N	Lbs. P_2O_5	Lbs. K_2O
A	100	40	100	60	0	0	100	100	100
B	100	40	100	60	0	60	160	100	100
C	100	40	100	60	60	0	160	100	100
D	100	40	100	60	60	60	220	100	100

For additional information, chiefly observational, a few extra plots were included which received no nitrogen except that which they could get from the soil itself; these "X" plots were given phosphate and potash similarly to those which received nitrogen fertilizer.

Since the area selected for the field test had been used for seedling testing for several years and was expected to show normal variability, 8 replicates of the 4 main treatments were specified, and a block arrangement of plots was used so that the results could be treated statistically by the analysis of variance. The layout is shown in Fig. 1. Plots in 7 of the blocks, each carried fifteen 60-foot rows of cane; in the eighth block only 12 rows per plot were available. One row was left unplanted between the sides of adjacent plots to reduce the "border effect" and to facilitate sampling and harvesting; a 7-foot space carrying the watercourses served a similar purpose between the ends of abutting plots.

Within each plot, 6 rows of cane (cross-hatched areas in Fig. 1) were designated as the "sampling station" from which all preharvest cane samples prior to the final field harvesting were taken; this was prescribed so that there would be no interference with the cane in the rest of the plot from which we wished to secure final and confirmatory yield data at the age of about 21 months.

From each of these sampling stations, *all* cane stalks growing within a 5-foot section of row were scheduled to be cut out at each of the following ages: 3½, 5½, 7½, 8½, 9½, 10½, 11½, 14½, 17½ and 20½ months. Thus the total plant material from a 5-foot section of cane row selected at random was our individual plot sample of the cane crop which was thereafter to be sub-sampled, prepared, and analyzed for certain constituents.

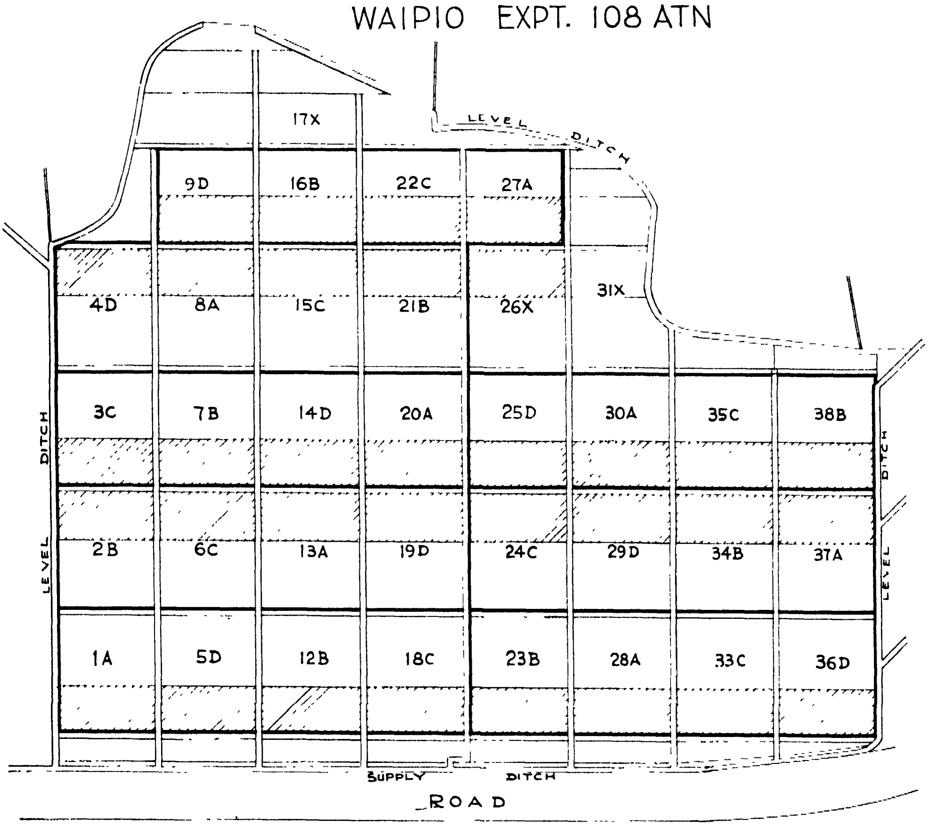

Fig. 1.

3. Field Culture:

After a thorough job of soil preparation and the laying out of the plots, seed of the variety 32-8560 was cut and planted during the week subsequent to July 26, 1940. Superphosphate was applied with the seed in every planting furrow and an immediate irrigation was given.

Subsequent germination in several of the first fifteen plots was exceptionally poor and a heavy replanting* was made at 3 weeks after the original planting in order to insure a full stand in all plots as early as possible.

Plot no.	Treatment	Per cent replant	Final yield TCA	Avg. yield TCA for treatment
1	A	70	112.9	110.9
2	B	10	129.4	120.0
6	C	10	117.7	120.2
7	B	15	116.3	120.0
8	A	20	103.1	110.9
9	D	20	110.6	122.7
12	B	70	119.6	120.0
13	A	65	110.6	110.9
14	D	50	122.4	122.7
15	C	30	118.0	120.2

After the first few rounds of irrigation, subsequent irrigation intervals were maintained at 250 elapsed day-degrees until January 21, 1942; thereafter, no further irrigations were made, and there was a total rainfall amounting to only 5.21 inches between this date and the final harvest.

Ammonium sulphate and muriate of potash were applied by hand on the cane row as scheduled, and an adequate weed control was maintained until the crop was well covered in.

4. *Observations at Periodic Harvests:*

The following observations which were recorded at the periodic harvests should be made a matter of record, since they may have a bearing on some of the measurements and interpretations which were made.

At first preharvest, at 3½ months: (1) The cane growth in the 32 plots which had received 40 pounds nitrogen to date was quite variable although the stand was excellent and stooling was heavy. (2) Sections of rows which had been heavily replanted were avoided when the cane sample was taken. (3) The color and growth of cane in "No N" or "X" plots were quite comparable with that in the N-fertilized plots.

At second preharvest, at 5½ months: (1) Considerable variation in development was still noted although growth in general had been exceptionally rapid. (2) The "No N" plots showed the yellowish-green leaf-color symptoms of nitrogen deficiency.

At third preharvest, at 7½ months: (1) All fertilized plots appeared strikingly uniform in appearance, stand, and stalk size. (2) Rapid growth had continued and stalks were still erect. (3) There had been a heavy mortality of the smaller shoots—evidently shaded out.

At fourth preharvest, at 8½ months: (1) The total green weight samples contained a very few small "second-season" shoots. (2) The millable cane was quite definitely "sweet to taste".

*** That this replanting was effective, may be seen from the fact that these plot yields, on their gross area basis at final harvesting were not significantly different from their respective treatment averages, *e.g.*:**

At fifth preharvest, at 9½ months: (1) A considerable number of suckers had made their appearance in the cane samples harvested. (2) The cane had now "gone down" in the "C" and "D" plots especially.

At sixth preharvest, at 10½ months: (1) The cane was now recumbent in all fertilized plots. (2) The cane sample included some sucker growth.

At seventh preharvest, at 11½ months: (1) The millable cane on large suckers made its first appearance in the cane samples.

At eighth preharvest, at 14½ months: (1) Big suckers with considerable millable cane made up from ¼ to ⅓ of the cane samples at this harvest. (2) All canes appeared by taste to have very little sugar—they were definitely disagreeable to taste.

At ninth preharvest, at 17½ months: (1) All stalks were in the best physical condition of any yet harvested; uniform big healthy tops, no dead cane stalks, and all seemed to have recovered their sugar, as they were "sweet canes" again at this time.

At tenth preharvest, at 20½ months: (1) Physical condition of cane was very poor; heavy winds had damaged tops and broken some stalks; tops appeared small and dry; some dead or dying tops were noted. (2) Sound canes were very sweet.

At the final field harvest, at 21½ months: (1) Secured almost perfect burns as cane was very dry. (2) Stalks appeared sound, heavy, and full of sugar. (3) Very little dead cane actually found.

5. *Experimental Procedure:*

Soil samples were taken each month from the row middle in a series of "X" plots which received no nitrogen, and from a "D" series which ultimately received the highest total amount of nitrogen fertilizer given. These were analyzed for their available nitrogen content by both the Mitscherlich and the R.C.M. methods of analysis.

Leaf-punch samples were taken periodically from the cane in every sampling station, according to the accepted procedure, and subsequently analyzed individually for their percentages of total nitrogen.

At each preharvest after the crop from each 5-foot section of row had been cut out, the cane was weighed to secure its total green weight. It was then divided into two comparable portions—one of these was topped and the millable cane therefrom weighed and crushed in the Cuban A mill[1] at Waipio, while the other portion was brought to Makiki and there subjected to further sub-sampling to reduce its bulk to an amount needed for the laboratory samples. In this sub-sampling procedure, great care was taken in sectioning and quartering the stalks, in cutting up the tops, and then in combining stalk and top segments in the proportion of their actual field weights to make certain that each laboratory sample was truly representative of the total cane sample harvested from each plot.

Laboratory samples of this total green weight were prepared for the determination by standard chemical methods of total nitrogen, chlorophyll, moisture, reducing sugars, sucrose, and total sugars; later, determinations of total phosphate and potash were also made. After the second preharvest, samples of young leaf blades and sheaths were also gathered for subsequent determinations of nitrogen, moisture, and sugars.

Most of the measurements and analytical data have been carefully examined and studied by the "analysis of variance". Positional effects have been largely removed from the total experimental error, but the residual errors still remain quite high, and indicate very definitely the heterogeneity which is always encountered in dealing with valid samples of a crop of sugar cane taken from the field. Thus although the number of replicate cane samples which were taken for analyses was generally greater than most plant investigators have worked with, many of the averaged differences measured must carry the statistical term of "non-significance", and interpretations therefrom will only be made tentatively until further evidence is obtained. No reasonable explanation is being rejected however, simply because a verdict of non-significance from the samples studied warns that one cannot be sure that the recorded differences are really the effects from the different nitrogen treatments. Data from the 3 "X" plots upon which no nitrogen fertilizer was applied have not been included in the statistical analysis, and the "minimum differences required", which are found listed in the tables in the Appendix, have reference only to differences between the 4 treatments which received 100 pounds per acre or more of nitrogen fertilizer.

BASIC SOIL ANALYSES

1. *Initial Soil Analyses:*

After all plots had been laid out, 2 composite soil samples, each made up from 10 soil-auger borings, were taken to depths of 0-12 inches and 12-24 inches, respectively, from each plot. Chemical analyses of these showed that we had placed the field test on a soil which had the following important characteristics:

	Depth 0–12"		Depth 12–24"	
Measurements	Average*	Range	Average*	Range
% total nitrogen	.114	.080 to .126	.084	.069 to .097
% total carbon	1.367	1.185 to 1.508	.852	.695 to 1.182
Ratio C/N	12.0	10.2 to 16.5	10.1	8.9 to 14.2
% available N (R.C.M.)	.0016	.0008 to .0037	.0006	.0005 to .0008
% available P_2O_5 (R.C.M.)	.0040	.0012 to .0090	.0005	.0004 to .0015
% available K_2O (R.C.M.)	.0031	.0025 to .0040	.0009	.0008 to .0012
P_2O_5 fixation index	65	50 to 85	90	80 to 90
pH	6.6	6.3 to 6.9	6.7	6.3 to 6.9

* From separate analyses of 35 soil samples.

From a subsequently taken composite soil sample, volume weight was found to be 1.06, for soil from either depth. Thus the total organic matter was estimated (C x 1.7) to be close to 68,000 pounds per acre surface-foot of soil, and total nitrogen was calculated at approximately 3,300 pounds per acre, to a depth of 12 inches. Hence this soil would not be considered a "high" nitrogen soil and response to nitrogen fertilization should be quite definite.

Biological tests (Mitscherlich) of soil fertility made on 2 composite soil samples taken within the experimental area indicated averages of the principal nutrients to be available in amounts as follows: 60 pounds nitrogen, 247 pounds phosphoric acid, and 633 pounds potash per acre.

A study of the soil analyses data from those 16 plots which received a total of 160 pounds of nitrogen, to find their relationships with their final cane yields, has shown no significant correlations. Correlation coefficients (*r*) between final yields and certain nitrogen measurements were calculated as follows:

(a) Per cent total nitrogen in soil and tons cane per acre: $r = -.40 \mp .21$
(b) Per cent available nitrogen in soil and tons cane per acre: $r = -.42 \mp .20$
(c) Carbon-nitrogen ratio of soil and tons cane per acre: $r = +.06 \mp .25$

2. Subsequent Soil Analyses:

Each month during the cropping period, soil samples to a depth of 12 inches were taken from each of 16 points located midway between the cane rows from plots of both Treatments X and D. Tested by a biological method (Mitscherlich) for their content of available nitrogen, we have a fair picture of the manner in which this soil was able to maintain a supply of nitrogen for this sugar cane crop. This is nicely shown in Fig. 2. The increase in available nitrogen during the first few months after plowing shows the effect which exposure to air and sunlight through good soil preparation has had on the availability of the soil nitrogen supply. Although this Waipio soil does not have a high total nitrogen content, its available nitrogen content increased and remained fairly high until December, when the cane roots were first observed to be within the soil sampling zones. Thereafter there was very little fluctuation, but apparently there was some soil nitrogen which continued to be available even within that soil zone which carried many active cane roots.

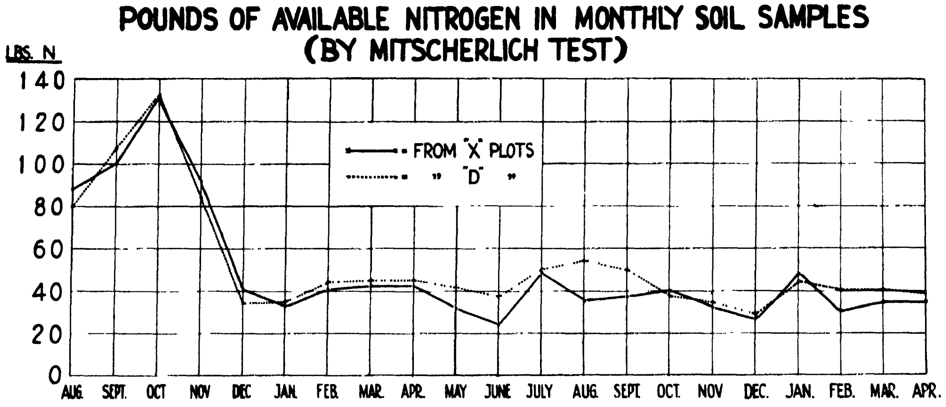

Fig. 2

TREATMENT EFFECTS

1. On Total Green Weights (Fig. 3). See footnote *:

In general there was a direct response to the amounts of nitrogen applied, *i.e.*, the more nitrogen applied, the more the total vegetative growth. The 60 pounds

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* The complete legend for this graphical presentation, identifying treatment, total pounds of nitrogen supplied, and month in which the final 60 pounds of nitrogen were applied, is shown on Fig. 3, and this same legend, somewhat abbreviated, is used consistently hereafter in all except Figs. 17, 20, 21, and 22 which have their own specific legends.

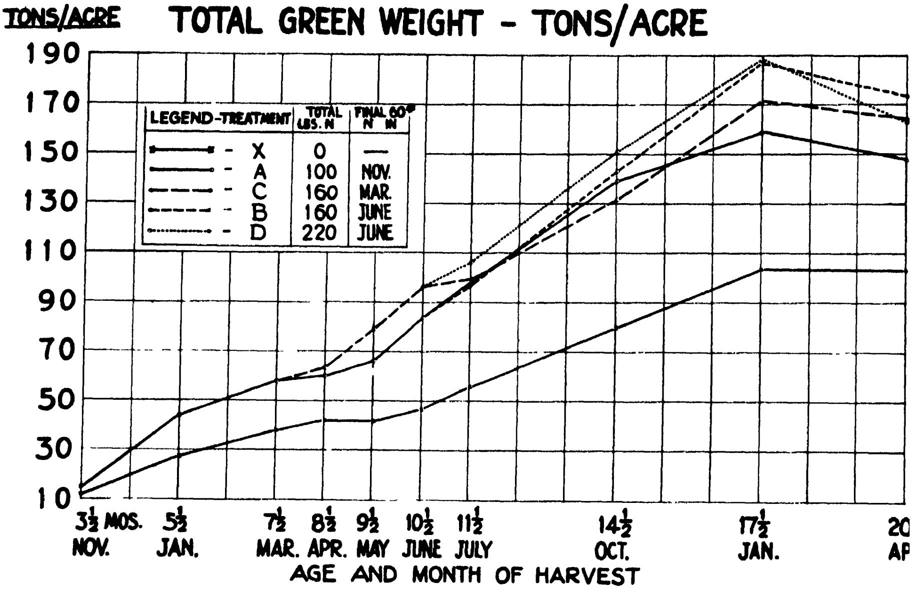

Fig. 3

of nitrogen applied in March (Treatment C) to crops which had already had 100 pounds were almost immediately effective and had significantly increased the total green weight by May; a further 60-pound application in June (Treatment D) maintained this accelerated growth rate through January, whereas production fell off somewhat when this June application was not made (Treatment C). Similarly, to that cane which had received only 100 pounds of nitrogen by June, an additional 60-pound application (Treatment B) produced increased tonnage thereafter.

The nature of this production of total vegetation is interesting. It was exceedingly rapid, even during the winter months—November to January—when the crop was only 3½ to 5½ months old. It apparently slowed down during March, April, and May but picked up again in early summer, and then maintained a rather constant rate throughout January. This constant increase in total green weight from June through January, especially by Treatments B and D which received nitrogen in June, is somewhat contrary to opinions that have been formed on the basis of growth measurement studies which usually show a greatly reduced rate of elongation by cane that is over one year old after September or October. After January subsequent development was apparently influenced by the "drying-off" period preceding harvest.

2. On Percentage of Tops (Fig. 4):

In this consideration, the top was defined as that portion of the stalk upwards from the growing point, plus all of the green leaves.

All plots showed a sharp decrease in their percentage of tops but it is quite doubtful that the differences noted between the treatments are significant. Between the ages of 5½ and 11½ months there was a reduction from about 40 to 20 per cent, and in the next 6 months a further decrease from 20 to approximately 10 per cent. This percentage of tops from the nitrogen-fertilized canes had decreased to between 8 and 9 per cent at the last preharvest at 20½ months.

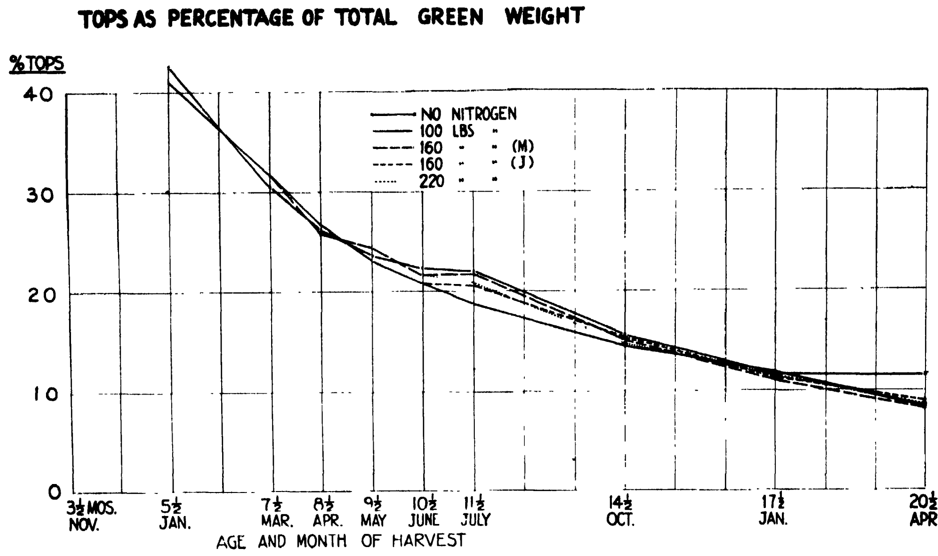

Fig. 4

3. On Per Cent Moisture in Total Green Weight (Fig. 5):

The effect of the nitrogen differentials on the per cent moisture in the crop is quite apparent. The higher nitrogen applications have consistently produced cane crops with a higher moisture content; this fact was particularly significant in the October harvests which apparently reflected combined effects with the high temperatures between July and October. It may also be an effect from the larger numbers of suckers which appeared in the October harvest on those plots which had received additional nitrogen in June.

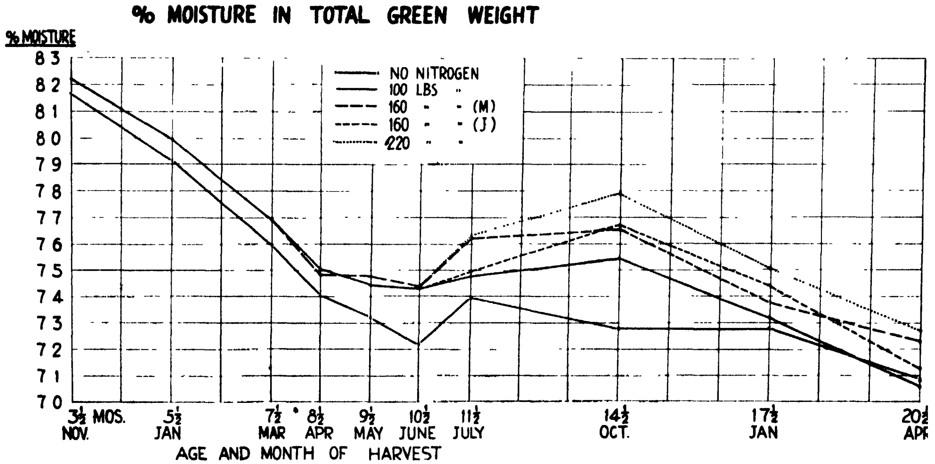

Fig. 5

Up to the age of 5½ months, during the winter months, the young crop of cane was very succulent, carrying about 80 per cent moisture. Between April and July, the moisture content remained around 75 per cent, but during the hot days of late summer there was a definite increase. This was followed by a decrease as the second winter approached, and a further decrease during the drying-off period preceding the April preharvest at 20½ months.

4. On Total Dry Weight (Fig. 6):

The picture for total dry weight does not differ widely from that of total green weight. The 60-pound nitrogen application made in March to a crop which had already received 100 pounds was effective and increased the dry weights harvested in May and June, but in subsequent harvests the effects from the nitrogen differentials were not significantly different. However, it does seem reasonable to feel (1) that the "A" treatment which received only 100 pounds of nitrogen did fall down in its yield of dry matter at both the 17½- and the 20½-month harvests, and (2) that the 220-pound nitrogen total on the "D" treatment did not produce the maximum yield of total dry matter at the maximum age harvested.

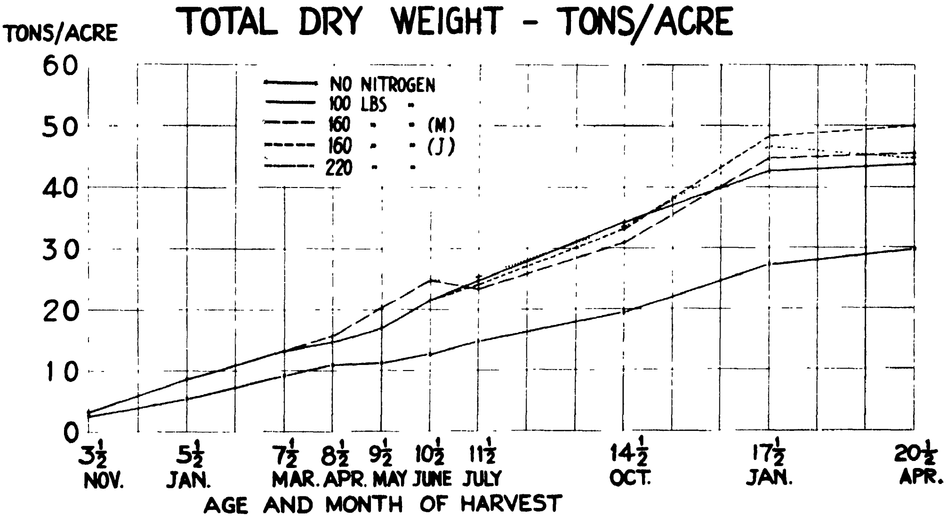

Fig. 6

5. On the Composition of the Total Dry Weight:

(a) Per cent Reducing Sugars (Fig. 7): Here we find a very clear-cut relationship, as the percentages of reducing sugars show a direct effect of the nitrogen that had been supplied; these treatment effects are highly significant at the last three preharvests.

Apparently the reducing sugars were generally high in the young cane during its first winter, then dropped sharply and remained lower throughout the first summer, regardless of the nitrogen fertilization. However, by October the nitrogen fertilizer had exerted its positive effects, and the reducing sugars were again quite high. After 14½ months there was a rapid decline which, except for the high nitrogen treatment (Treatment D), brought the percentage down below 2 per cent at the last preharvest.

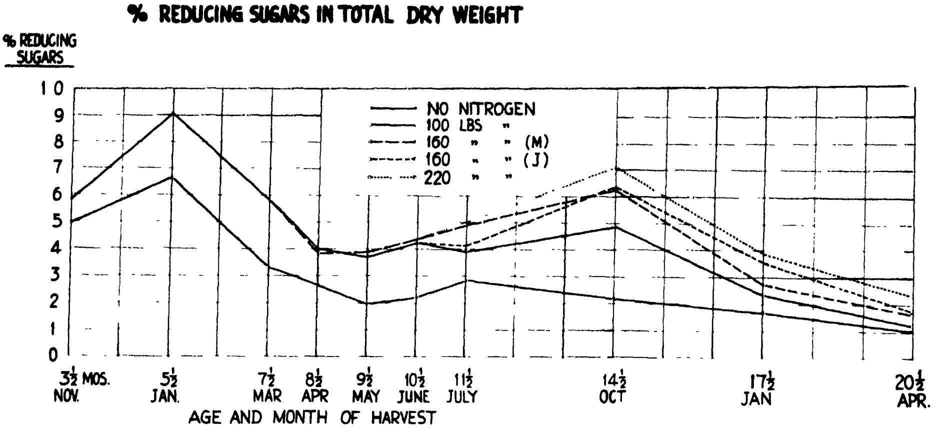

Fig. 7

(b) Per cent Sucrose (Fig. 8): This measurement, as expected, shows an inverse relation with the per cent reducing sugars. Effects of treatment although not statistically significant appear to be positive at 14½ and 17½ months, but are somewhat confused at 20½ months when they are all fairly close together, regardless of their respective nitrogen treatments.

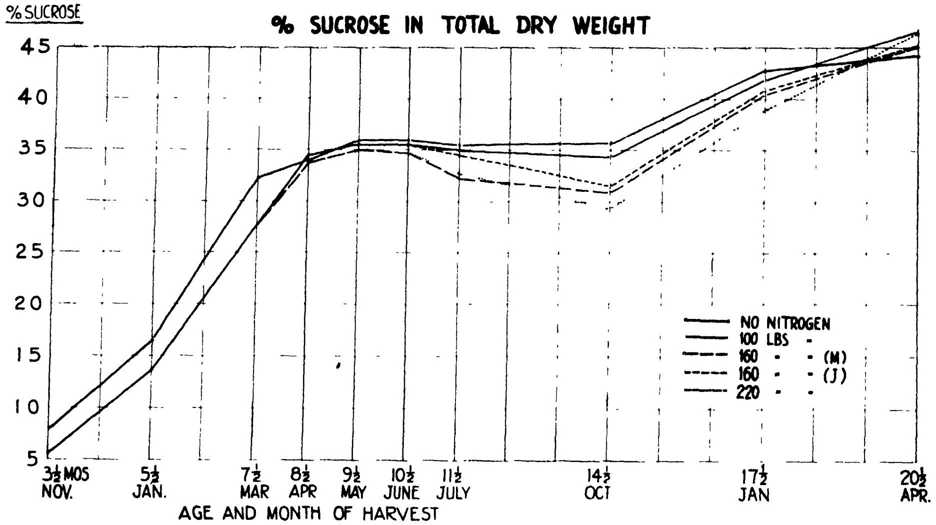

Fig. 8

A very rapid rise in per cent sucrose came during the first 7 or 8 months and then no further increase in concentration occurred until after the warm summer and fall seasons in which fast growth was taking place. There was a very considerable pickup in per cent sucrose again in January, and this, in spite of the fact that both total green and dry weights show parallel increases. Thus it is apparent that we can have an increase in cane and a corresponding and simultaneous increase in the per cent sucrose in this same cane. A further increase between January and April was made while the yields of both green and dry weight were being checked by the drying-off procedure prior to the final field harvesting.

A very good idea of the inverse relationship between the per cent sucrose and per cent moisture is shown in Fig. 9. Here we see that the high nitrogen applications have resulted in cane with high moisture and low sucrose whereas the smaller nitrogen supplies have given us cane with a lower moisture and higher sucrose content.

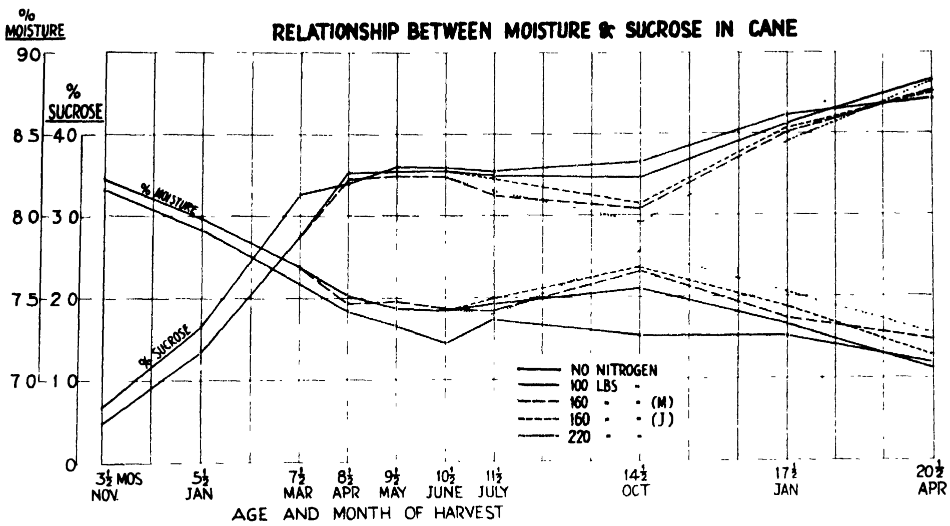

Fig. 9

(c) Per cent Total Sugars (Fig. 10): This graph is naturally dominated by the per cent sucrose in the dry weight. It shows some influence of the nitrogen differentials, *i.e.*, lower percentages from the higher nitrogen applications, but there are

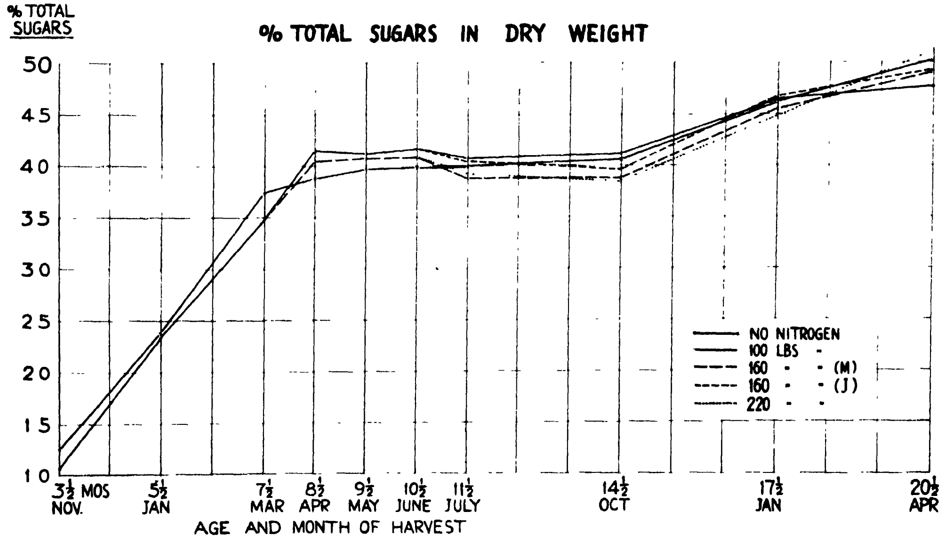

Fig. 10

some inconsistencies, so the effects are not clear. Although the experimental errors which are involved in these analyses were quite low, none of the treatment effects were found to be statistically significant. Perhaps factors other than nitrogen exert a greater influence on the percentage of total sugars; either age or season or both may play the major role. Worthy of note is the fact that regardless of treatment differences the percentage of total sugars, which had increased at a rapid rate prior to April, remained at the same level during the subsequent 6 months of higher temperatures and longer days.

(d) Per cent Nitrogen (Fig. 11): With but a single exception Fig. 11 shows that the nitrogen content of the total dry weight reflected the amounts of nitrogen applied. Statistically, the treatment effects are highly significant.

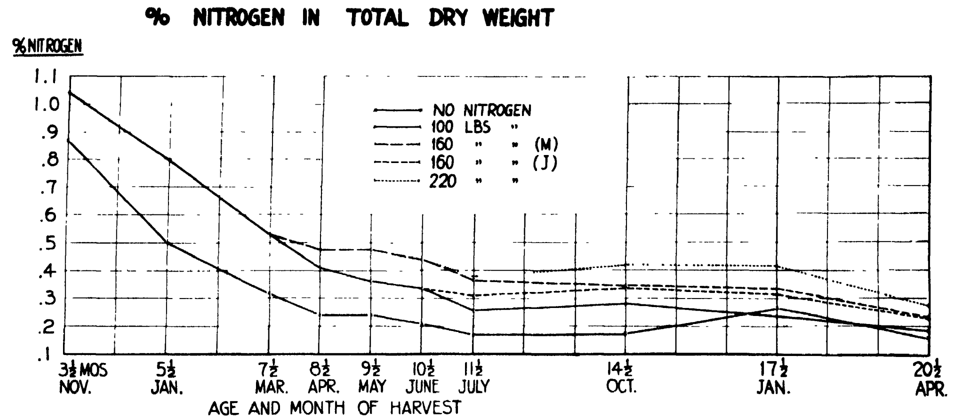

Fig. 11

In general the per cent N in the fertilized cane dropped from 1.0 to 0.5 per cent between 3½ and 8½ months; thereafter only a slight further reduction took place that was not the effect from the nitrogen applications.

At the age of 7½ months (in March), we found .53 per cent N in the total dry weight of the crop samples which had been fertilized with nitrogen at 100 pounds per acre. At 10½ months (in June), this figure had dropped to .33 per cent N when no additional nitrogen had been supplied in March. However, when another 60 pounds of nitrogen was given in March (Treatment C), a nitrogen percentage of .43 was found in the June samples. Furthermore, an application of 60 pounds per acre made in June to cane which had only received a total of 100 pounds per acre to date (Treatment B) was subsequently effective in holding the per cent N in the crop to a level quite comparable with Treatment "C". Since it was found that these two treatments—B and C—produced the optimum final sugar yields at 21½ months, it might be important to record here the following facts for future reference:

(1) At the age of 7½ months (in March), a crop which had already received

a total of 100 pounds of nitrogen some 4 months previous, and which showed only .53 per cent N in its total dry weight, responded favorably to an additional 60 pounds of nitrogen per acre (Treatment C).

(2) At the age of 10½ months (in June), a crop which had received 100 pounds of nitrogen 4 months previous, and which showed only .33 per cent N, responded favorably to an additional 60 pounds of nitrogen (Treatment B).

(3) At the age of 10½ months (in June), a crop which had then received a total of 160 pounds of nitrogen, and which showed .43 per cent N in its total dry weight (Treatment C), *did not respond* to an additional 60 pounds of nitrogen (Treatment D) when it was harvested at 21 months of age.

Although this difference found in June, between a percentage of .33 in Treatment "B" which showed an economic response to a subsequent 60-pound application of nitrogen, and .43 in Treatment "C" which did not show a profitable response to another 60 pounds in June, is quite small, there is no reason why it cannot be reliably identified as an actual difference if truly representative samples of the crop are adequately secured for the nitrogen analysis. (In our case 4 samples would have identified .33 per cent and .43 per cent N as significantly different amounts.)

(c) Per cent Phosphoric Acid (Fig. 12): The March application of ammonium sulphate to Treatment C appears to have resulted in a higher concentration of phosphoric acid in the total dry weights harvested in May and June. This may have been an effect from the sulphate on the soil phosphate rather than from the nitrogen in this fertilizer. Thereafter, until the final preharvest, other differences

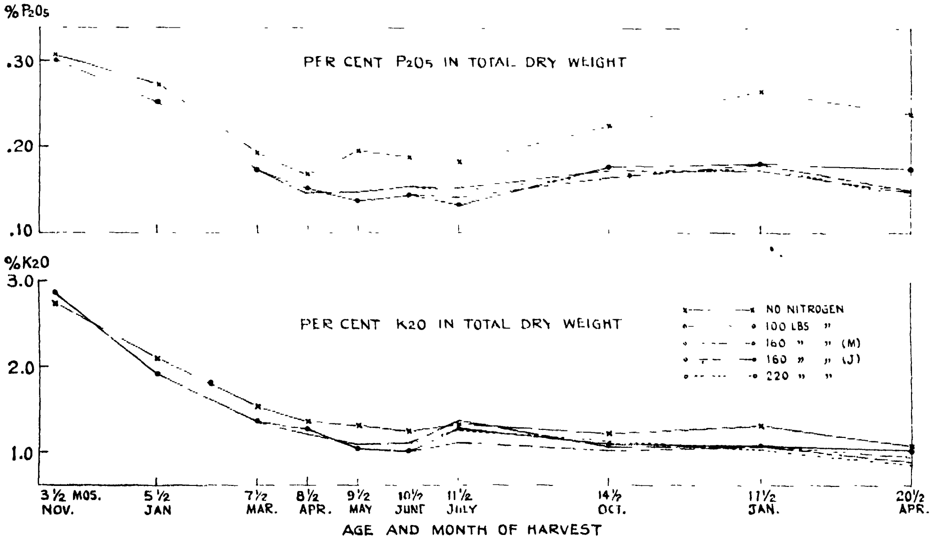

Fig. 12

found in the percentages of P_2O_5 in the total dry weight of those crops which received nitrogen fertilizer were probably not the effects from the different nitrogen treatments. It is quite clear however, that the percentage of P_2O_5 in cane from the "no nitrogen" plots was consistently higher than that found in the nitrogen-fertilized cane, and at the final harvest, the low-nitrogen "A" plots also had cane with a higher concentration of phosphate than the more adequately nitrogen-fertilized plots. This is a quite commonly observed relationship between nitrogen and phosphate when the available supply of either one is actually deficient.

(f) Per cent Potash (Fig. 12): An effect from differences in applied nitrogen on the per cent K_2O in the total dry weight was not definitely established. There is a suggestion that the June applications of nitrogen to Treatments B and D, which stepped up the concentrations of nitrogen found thereafter, may have resulted in a slightly lower per cent K_2O in the crop harvested the following month, but, if so, this was only a temporary effect.

As was the case with per cent P_2O_5, the no nitrogen "X" plots also produced a crop with a higher percentage of K_2O than the nitrogen-fertilized crops.

The trends in the curves for per cent K_2O in dry weight of the preharvest samples are in general quite similar to those for both per cent N and per cent P_2O_5; apparently the concentrations of all 3 plant foods decrease rapidly during the first 10 months and thereafter remain fairly constant as long as the crop is kept growing normally.

(g) Total Nutrition and Nutrition Ratios: In Table I we have recorded data for future reference and hopeful interpretation. Plant physiologists have suggested that since chemical analyses of selected plant samples will indicate concentrations of the major nutrients in the crop, they can be used to guide fertilizer practices; ordinarily use is made of only a specific part of the crop, such as certain young leaves or stems for the plant sample to be analyzed. Since we had secured samples of the crop which included entire plants (except trash and roots), and as our gross analyses of these crop samples at the periodic harvests were sufficiently sensitive to reflect the different nitrogen treatments, these analyses ought to contain pertinent information if we can identify,their relation with the final sugar yields harvested. Hence in Table I we have recorded for each treatment at each age harvested, the separate percentages of N, P_2O_5, and K_20 which were found in the total dry weight from the crop samples, and the sum total of these 3 percentage figures as the total nutrition. Then we have reduced these percentage figures to their respective milligram equivalents and calculated (*a*) the respective ratios of the N, P_2O_5, K_2O concentrations, and also (*b*) the ratio of $P_2O_5+K_2O$ to N. Since we had secured actual comparative yields of total dry weights, we are also able to present the total nutrition for each treatment in terms of total pounds of N, P_2O_5, and K_2O in the dry weight harvested, and to indicate the relative proportions of this total nutrition which were contributed by its three components. Unfortunately we fail to find sufficiently consistent relationships with the final sugar yields in these data to accept them at this time for reliable guidance in nitrogen fertilization of sugar cane crops.

TABLE I

NUTRIENT COMPOSITION OF TOTAL DRY WEIGHTS

Treatment	Age (mos.)	Lbs. N to date	Percentages in total dry weight						Pounds per acre in total dry weight	
			N	P_2O_5	K_2O	Sum ($N+P_2O_5+K_2O$)	Ratio* $N-P_2O_5-K_2O$	$P_2O_5+K_2O \div N$	Total lbs. N, P_2O_5, K_2O	Proport. (%) $N-P_2O_5-K_2O$
X	3½	0	.866	.307	2.755	3.928	46-10-44	1.16	160	22- 8-70%
A	3½	40	1.048	.304	2.869	4.221	50- 9-41	.99	215	25- 7-68%
X	5½	0	.503	.275	2.181	2.959	38-12-50	1.62	339	17- 9-74%
A	5½	100	.797	.254	1.923	2.974	52-10-38	.91	524	27- 9-64%
X	7½	0	.311	.191	1.568	2.070	35-13-52	1.87	383	15- 9-76%
A	7½	100	.534	.170	1.385	2.089	51-10-39	.96	555	26- 8-66%
X	8½	0	.244	.164	1.363	1.771	33-13-54	2.07	382	14- 9-77%
A	8½	100	.406	.148	1.238	1.792	47-10-43	1.13	533	23- 8-69%
C	8½	160	.475	.146	1.222	1.843	51-10-39	.95	576	26- 8-66%
X	9½	0	.243	.196	1.333	1.772	32-15-53	2.11	382	14-11-75%
A	9½	100	.358	.136	1.040	1.534	48-11-41	1.09	516	23- 9-68%
C	9½	160	.474	.145	1.080	1.699	54-10-36	.86	680	27- 9-64%
X	10½	0	.207	.185	1.222	1.614	30-16-54	2.29	425	13-11-76%
A	10½	100	.335	.141	1.081	1.557	45-11-44	1.21	675	21- 9-70%
C	10½	160	.431	.152	1.149	1.732	50-10-40	1.00	860	25- 9-66%
X	11½	0	.172	.180	1.340	1.692	25-16-59	2.94	493	10-11-79%
A	11½	100	.254	.130	1.330	1.714	35-11-54	1.86	848	15- 8-77%
B	11½	160	.309	.140	1.140	1.589	42-11-47	1.37	772	20- 8-72%
C	11½	160	.365	.150	1.360	1.875	43-10-47	1.36	866	20- 8 72%
D	11½	220	.372	.150	1.290	1.812	44-10-46	1.27	915	21- 8-71%
X	14½	0	.172	.223	1.206	1.601	26-20-54	2.86	708	11-14-75%
A	14½	100	.276	.174	1.113	1.563	39-14-47	1.58	1071	18-11-71%
B	14½	160	.341	.163	1.012	1.516	46-13-41	1.17	1009	22-11-67%
C	14½	160	.346	.171	1.064	1.581	45-13-42	1.21	974	22-11-67%
D	14½	220	.427	.167	1.160	1.754	49-11-40	1.04	1198	24-10-66%
X	17½	0	.251	.263	1.308	1.822	31-20-49	2.18	1018	14-14-72%
A	17½	100	.236	.178	1.072	1.486	36-16-48	1.80	1255	16-12-72%
B	17½	160	.314	.178	1.073	1.565	43-14-43	1.36	1498	20-11-69%
C	17½	160	.329	.173	1.071	1.573	44-14-42	1.28	1419	21-11-68%
D	17½	220	.413	.175	1.062	1.650	50-12-38	1.02	1551	25-11-64%
X	20½	0	.159	.239	1.205	1.603	24-21-55	3.15	959	10-15-75%
A	20½	100	.185	.171	1.056	1.412	31-17-52	2.25	1212	13-12-75%
B	20½	160	.231	.148	.959	1.338	38-15-47	1.62	1332	17-11-72%
C	20½	160	.234	.148	.924	1.306	39-15-46	1.55	1183	18-11-71%
D	20½	220	.274	.143	.847	1.264	45-14-41	1.23	1150	22-11-67%

* Based on chemical equivalents.

6. On the Composition of Leaves and Crusher Juices:

(a) Per cent Nitrogen in the Leaf-punch Samples (Fig. 13): Since we had rather hoped that this index of nitrogen from the active green leaves would be a useful guide to nitrogen fertilization, samples from the crops were taken more frequently for total nitrogen analyses. The results are best discussed after a study of Fig. 13.

There is no doubt that the leaf-punch analyses have reflected the different levels of nitrogen in the crop which resulted from the different nitrogen supplies made available. Nearly all of the differences resulting from the different nitrogen totals are statistically significant, and the effect of changing the nitrogen supply was identified from the leaf analyses within a month after each nitrogen application. This indicates both the rapidity with which applied nitrogen fertilizer gets into the crop, and the reliability with which the leaf-punch nitrogen index identifies a changed nitrogen status.

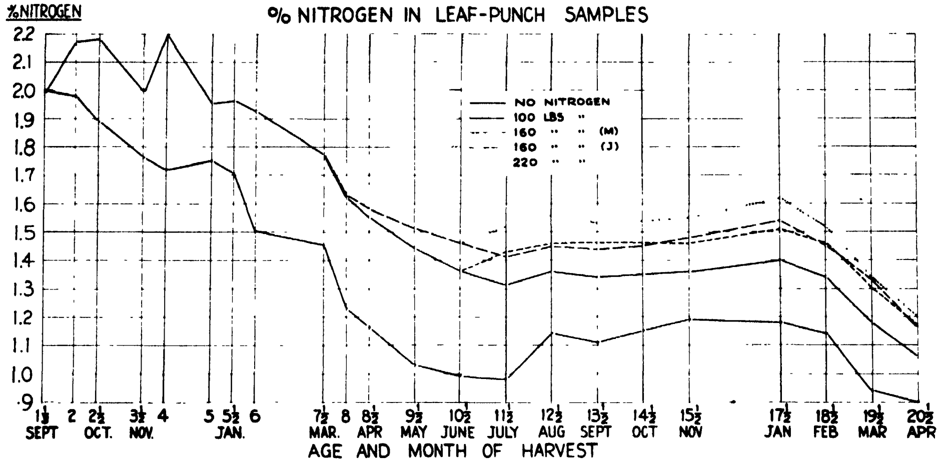

Fig. 13

The coefficients of variability for the leaf-punch nitrogen analyses were found to be quite low, seldom running over 5 per cent, and significant differences in per cent N of between 0.05 and 0.07 per cent were measured with 8 replicates of the leaf-punch samples. This indicates a very low variability in the specific leaf material analyzed and also a low analytical error. Thus the method or procedure which has been laid down by Yuen and Hance (6) for studying the nitrogen in specific cane leaves is believed to be highly reliable, but the interpretation of its results is another matter.

The percentage of nitrogen found in these leaves up to the time the crop was 5½ months old was fairly close to the 2.0 per cent level which has been suggested as an adequate nitrogen level for samples from active cane leaves under 6 months of age. The drop to about 1.75 per cent at 7½ months in March seemed to be a normal decrease. Thereafter the "A" plots continued to drop and at 10½ months were below the 1.5 per cent N level at which it seemed desirable to keep the per cent N in cane leaves until the crop was one year old. Even the additional 60 pounds of nitrogen applied in March failed to stop the decline, although it did slow it up somewhat. An unexpected "status quo" was experienced by all treatments between June and October, and the continued decline in nitrogen was stopped whether or not the cane had received more nitrogen fertilizer in June, so the levels at 17½ to 18 months were somewhat higher than believed desirable. This must have been due to a late contribution of nitrogen made by the soil; perhaps we saw a suggestion of this effect in the monthly soil analyses (Fig. 2). After October when the crop was 17½ months old, a further decline in the per cent N of the leaf-punch samples was quite abrupt and at the last preharvest, none of the treatments were above 1.2 per cent; this indicated that their nitrogen supplies had all been fairly well used up.

But to return to our chief interest in Fig. 13 which is to determine whether the leaf-punch nitrogen data could have been used to tell us in March or in June that the crop to be harvested a year hence would or would not need more than the basic 100 pounds of nitrogen which it had already received.

In March when we found 1.77 per cent N in the leaf samples, we had apparently an inadequate supply indicated for a 21-month crop, as Treatment A which received no more nitrogen eventually proved less productive of commercial sugar than Treatment C which received 60 pounds more nitrogen in March.

In June at 10½ months, the leaves from Treatment A showed only 1.36 per cent N. Apparently this was also too low because when 60 pounds more nitrogen were applied to make Treatment B, the ultimate gain in sugar was highly significant and profitable. However, Treatment C which had already received 160 pounds of nitrogen before June and which now showed a leaf-nitrogen percentage of 1.46 apparently had enough nitrogen, for an additional nitrogen fertilization then did not result in any final increase in sugar. From this it would appear that a nitrogen index from leaf-punch samples of 1.36 per cent at 10½ months in June represented an inadequate nitrogen composition, but that an index of 1.46 per cent was quite adequate for the 21-month crop of 32–8560 cane. This difference between 1.36 and 1.46 is a very small one, and even though it can be measured as significant, we hesitate to suggest these narrow limits for guidance in nitrogen fertilization until considerably more verification of these data is obtained, because that levelling off of the per cent nitrogen in the leaves between June and October may or may not always occur.

Reference to Fig. 13 does show a very clear-cut difference between the crop which received no nitrogen fertilizer (Treatment X) and the treatments which received nitrogen. Hence there is little doubt but that the nitrogen indices from the "X" plots, which were relatively low after the second month and definitely low at 7½ months, indicated a need for more nitrogen, but this same indication could be observed in the easily visible leaf symptoms also. Furthermore after the crop has already been given a fair amount of nitrogen, it is apparently not going to be as easy to interprete this same nitrogen index for guidance of additional nitrogen needs—and this is the specific guidance we need.

(*b*) *Other Foliar Indices* (*Fig. 14*): Clements (1) has suggested the use of certain foliar indices to show the kind of cane growth which is being made, with the thought that certain corrective measures can be applied to change the type of growth, if it is undesirable. As a supplementary study, we were able to secure measures of the suggested primary and secondary indices from 3 "X" plots but from only 2 plots each from Treatments A, B, C, and D. For ready reference the results from the analyses made on blades and sheaths of the active green-leaf samples are shown graphically in Fig. 14.

Our chief interest in these data is centered on the leaf analyses which were made from the April-May-June samples, since 3 nitrogen differentials were then in effect; furthermore, corrective measures, if needed, would have to be applied at about this time. The picture is none too clear, so perhaps we are justified in averaging the data from these 3 preharvests. When this is done we have the following averages to reconcile with their associated final field yields:

				Averages from April-May-June harvests					
							Final field yield averages		
Plots	No. of plots sampled	Pounds N applied to date	% total sugars in sheaths	% dry matter in sheaths	% total nitrogen in blades		TCA	Y%C	TSA
X	3	0	10.403	29.2	.666	(X)	72	14.0	10.9
A & B	4	100	10.614	27.0	.873	(A)	103	14.0	14.4
						(B)	121	12.9	15.5
C & D	4	160	11.841	27.2	.970	(C)	117	13.2	15.3
						(D)	121	13.0	15.5

Considering first the suggested primary index, *i.e.*, the percentage of total sugars in the dry weight of the young leaf sheaths, we note practically no difference

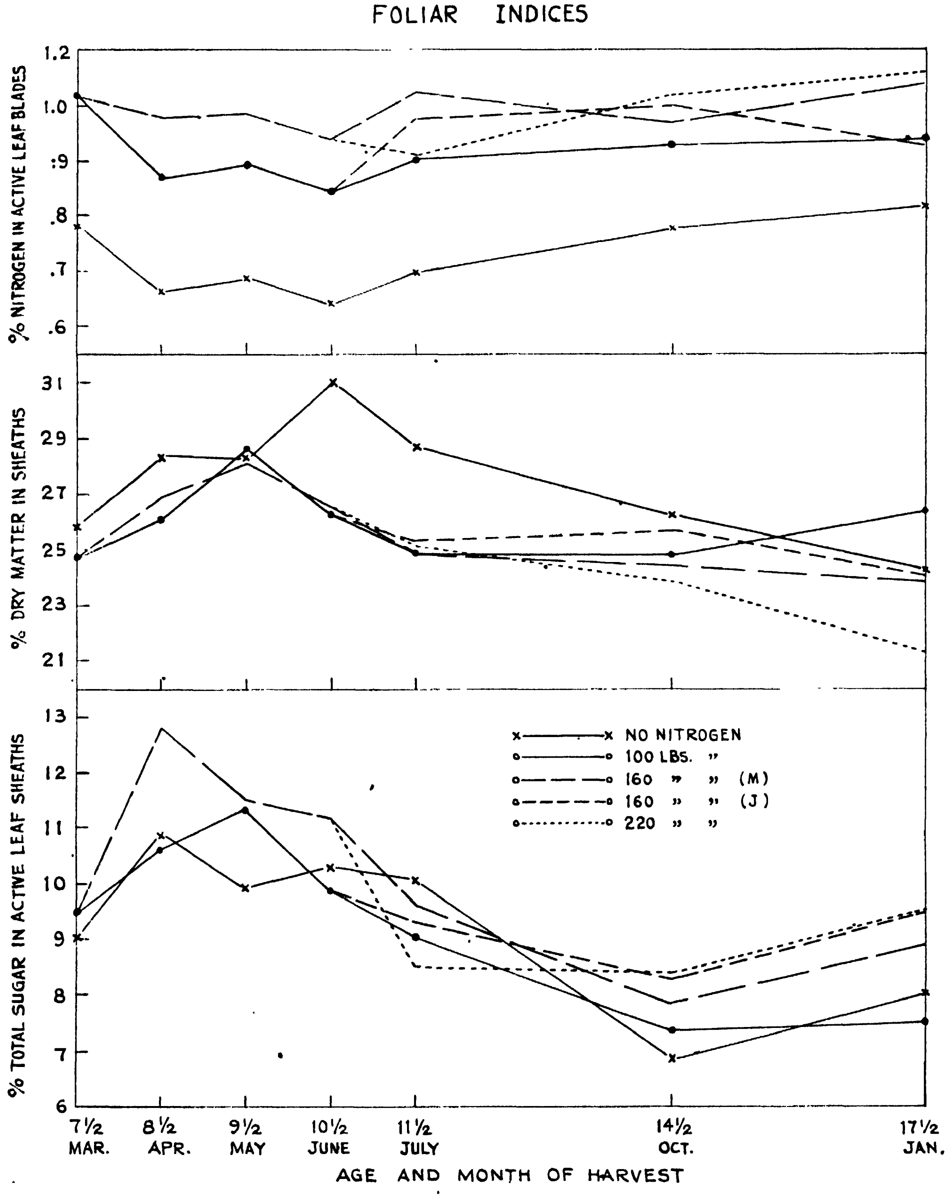

Fig. 14

between the "X" and the "A and B" plots, but a slightly higher sugar index from the "C and D" plots. Since we actually harvested more cane and sugar from both the A and B than from the X plots, it is difficult to see any relation between this primary index and the final yields which were harvested from the specific plots the leaf samples were taken from. Furthermore, although the leaf sheaths from the C and D plots at this time carried a higher concentration of total sugars than the A and B plots, the final cane and also sugar yields were higher from the C than from the A plots, so apparently the higher carbohydrate status of these leaf sheaths was not due to a slower growth of the cane. As a matter of fact the per cent total sugars in sheaths from Treatment C was higher than from Treatment A in every sample analyzed.

Although a ratio of 12 to 1 was found for per cent total sugars in sheaths to per cent total nitrogen in blades for both the A and B and the C and D plots, apparently the 10.6 per cent sugars and .87 per cent nitrogen for the A and B plots were not indicative of a satisfactory carbohydrate or nitrogen status at this stage, for an additional 60-pound application of nitrogen immediately thereafter made Treatment B better than Treatment A. On the other hand, when 11.8 per cent sugars and .97 per cent nitrogen were found, a similar 60-pound application of nitrogen did not make Treatment D any better than C.

Using the 40 samples collected at the March, April, May, June, July harvests, we find several correlations which should be recorded here for future reference. The following correlation coefficients were obtained:

(*a*) Between % N in green-leaf blades and in sheaths of same leaves.... $r = +.71 \mp .08$†
(*b*) Between % dry weight in leaf sheaths and % total sugars in same sheaths .... $r = -.38 \mp .14$*
(*c*) Between % moisture in leaf sheaths and % N in leaf blades from duplicate samples .... $r = +.15 \mp .15$
(*d*) Between % N in leaf blades and per cent total sugars in leaf sheaths from duplicate samples .... $r = +.03 \mp .16$
(*e*) Between % N in leaf blades and per cent N in total dry weight from duplicate samples .... $r = +.06 \mp .16$
(*f*) Between % total sugars in leaf sheaths and per cent total sugars in total dry weight from duplicate samples.......................... $r = +.33 \mp .14$*

* Significant. † Highly significant.

Apparently we shall need further study of these specific foliar indices before we can hope to be guided by them in our adjustment of nitrogen fertilization. The extent of the variation in the percentage of total sugars found in the leaf sheaths, as indicated below, from separate replicated plot samples, makes it appear that this measurement is subject to some rather wide fluctuations; this can make its interpretation very difficult.

EXTENT OF VARIATION IN PER CENT TOTAL SUGARS IN LEAF SHEATHS OF CANE FROM REPLICATED PLOTS

Plot No.	From plots which had received 100 pounds N/acre — Sampled in				Plot No.	From plots which had received 160 pounds N/acre — Sampled in		
	March	April	May	June		April	May	June
23	8.32	9.69	7.76	8.44	24	14.07	9.31	10.56
28	8.62	9.60	12.42	10.25	29	11.11	11.51	8.85
34	9.06	11.19	12.92	10.97	33	14.67	13.86	13.70
37	10.32	12.12	12.47	9.53	36	11.30	11.37	11.79
24	8.87							
29	9.54							
33	11.29							
36	9.98							

(*c*) *Per cent Nitrogen in the Crusher Juices (Fig. 15):* This is one of the clearest pictures we obtained; the effect from nitrogen applied to the cane upon the nitrogen found in its crusher juice only one month after application is positive, and is measured with high statistical significance at each preharvest. From the curves in Fig. 15, tentative criteria for nitrogen deficiency or nitrogen sufficiency can be recorded for further verification. For instance, at 7½ months .030 per cent nitrogen in the crusher juice was too low and a better sugar yield was finally secured when an additional 60-pound application of nitrogen held this level at or above .030 per cent until 10½ months. But at 10½ months, a figure of .030 per cent was an index of an adequate amount of nitrogen for the remainder of the 21-month crop, for no gain in sugar was secured when another 60 pounds of nitrogen were supplied in June. However, the figure of .018 per cent nitrogen in juice at 10½ months was apparently too low, and an extra 60 pounds of nitrogen were needed to keep this figure from still further decline during the rest of the 21-month crop period, and to thereby enable Treatment B to produce more sugar than Treatment A.

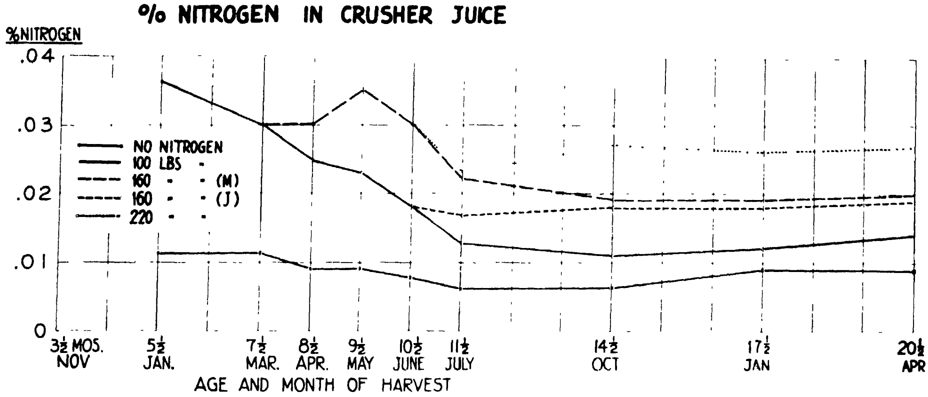

Fig. 15

So, as was the case with per cent nitrogen in the leaf-punch samples, and per cent nitrogen in total dry weight, before we can use the composition of nitrogen in crusher juices as a guide for further nitrogen needs, we must obtain many more related measurements concerned with plant nitrogen analyses and their associated final sugar yields.

(*d*) *On the per cent Chlorophyll in the Green Leaves (Fig. 16):* Leaf color has always been used by our planters as a qualitative index of the nitrogen status of their crop. Since this color is dominated by the chlorophyll in the leaves, a numerical measure of the chlorophyll content should be a more exact piece of information than a personally influenced descriptive color term.

From Fig. 16 it will be noted that the per cent chlorophyll of the "X" plots at the first preharvest was lower than that of the fertilized cane, although our observations at 3½ months had not revealed any significant color difference; after this age however, this color difference was easily seen.

In general the chlorophyll content of the leaves was increased with each application of nitrogen. All treatments showed the expected seasonal influences, being high in the winter months and low during the longer sunny days of summer. The

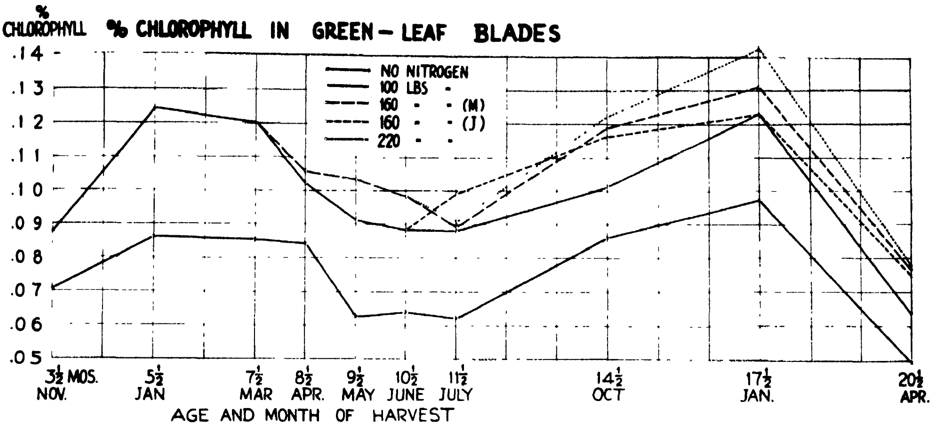

Fig. 16

rapid falling off at the end of the crop was undoubtedly due to the effects of the "drying-off" period.

Like other percentage data which were recorded, it is still too early to attempt an interpretation of the differences in the percentage of chlorophyll that were found between 7½ and 10½ months.

7. *On the Yields Per Acre:*

All data concerned with yields per acre are subject to the high experimental error associated with the harvesting of small unit plots of field-grown sugar cane. Thus although the block variance was identified and separated from the error variance, the residual or experimental error is still high. In the April, May, and June preharvests, 16 replicates of two different nitrogen treatments, *i.e.*, 100 and 160 pounds per acre were available for average yields; in the last 4 preharvests 8 replicates of the 4 nitrogen totals were available. In spite of these numbers, few of the measured yield differences are proved effects of treatments and so their interpretation must not be considered final.

(*a*) *Reducing Sugars, Sucrose, and Total Sugars:* Following the application of the first nitrogen differential in the March fertilization, we find increases in tons per acre of both reducing sugars and sucrose from the crop which had received a total of 160 pounds of nitrogen; this resulted in significant increases in total sugars in the May and June preharvests of 1.19 and 1.15 tons, respectively, over the crop which had received only 100 pounds of nitrogen.

After the June application when the differential amounts of nitrogen became effective, an interesting story of the effects of nitrogen upon sugar accumulation by a cane crop is unfolded. Each application and increase in nitrogen produced an increase in tons of reducing sugars. The 60-pound nitrogen application in June produced more reducing sugars in the preharvests at 14½, 17½, and 20½ months than the comparable nitrogen application that was made earlier—in March. On the other hand the yields of sucrose and total sugars per acre appear to have been affected somewhat differently. At 11½ and 14½ months, Treatment "A" which had received only 100 pounds of nitrogen had produced as much or more sucrose and total sugars per acre as plots which had received more than 100 pounds of nitrogen. At 17½ months, Treatment "A" had fallen below Treatment "B" (160 pounds N) which then assumed the lead and held it again at 20½ months; and Treatment "C" which had its last 60 pounds of nitrogen in March was never quite able to catch Treatment "B" (last 60 pounds in June) in its yields of sucrose or total sugars.

Very little difference in total sucrose and in total sugars per acre was measured at 17½ or at 20½ months between crops which received 100 pounds nitrogen, 160 pounds nitrogen early, or 220 pounds nitrogen per acre. These assumptions are made from the data in Table II.

TABLE II

SUGARS IN TOTAL DRY WEIGHT—TONS PER ACRE

			July harvest—11½ mos. Tons per acre			October harvest—14½ mos. Tons per acre		
Treatment	Total lbs. N applied by June	Last 60 lbs. N applied	Reducing sugar	Sucrose	Total sugars	Reducing sugar	Sucrose	Total sugars
A	100	November	.95	8.68	10.09	1.69	11.78	14.08
B	160	June	1.00	8.44	9.88	2.06	10.59	13.21
C	160	March	1.16	7.58	9.13	1.90	9.58	11.97
D	220	June	1.27	8.33	10.03	2.45	9.92	12.90

	January harvest—17½ mos. Tons per acre			April harvest—20½ mos. Tons per acre		
	Reducing sugar	Sucrose	Total sugars	Reducing sugar	Sucrose	Total sugars
A	1.03	17.54	19.49	.53	20.41	22.01
B	1.63	19.68	22.34	.82	22.57	24.59
C	1.22	18.14	20.31	.75	20.70	22.52
D	1.76	18.26	20.98	1.03	20.64	22.76

(*b*) *Millable Cane and Recoverable Sugar (Fig. 17):* Our chief interest in these data lies in the last 4 harvests, since our plantations have been known to take off crops which have approximated the ages that are represented by these later harvests. It is in these data that we have the real "pay-off" for the planter, and what a changing picture it is!

It should be recorded here that all of the preharvest yields have been reported on their actual *net* area basis of 25 square feet per plot, and hence they should and will be found approximately 24 per cent higher than they would be if calculated on their gross area basis. This can be seen from the following reconciliation between the cane yields as reported for the April preharvest at 20½ months and the actual final field yields of cane which were obtained within the next 3 to 5 weeks and which were reported on a gross area basis:

Treatment	Last preharvest sample TCA (net area)	Final field yield TCA (gross area)	Per cent difference
A	136.3	110.9	+22.9
B	158.0	120.0	+31.7
C	151.2	120.2	+25.8
D	149.6	122.7	+21.9
X	91.2	71.8	+27.0
		Average	+25.8

At the age of 11½ months the optimum yield of recoverable sugar was obtained from the crop which had received only 100 pounds of nitrogen per acre, and this shows a very profitable increase over zero nitrogen. There was very little difference in the cane yields between the 4 treatments which had received nitrogen, even

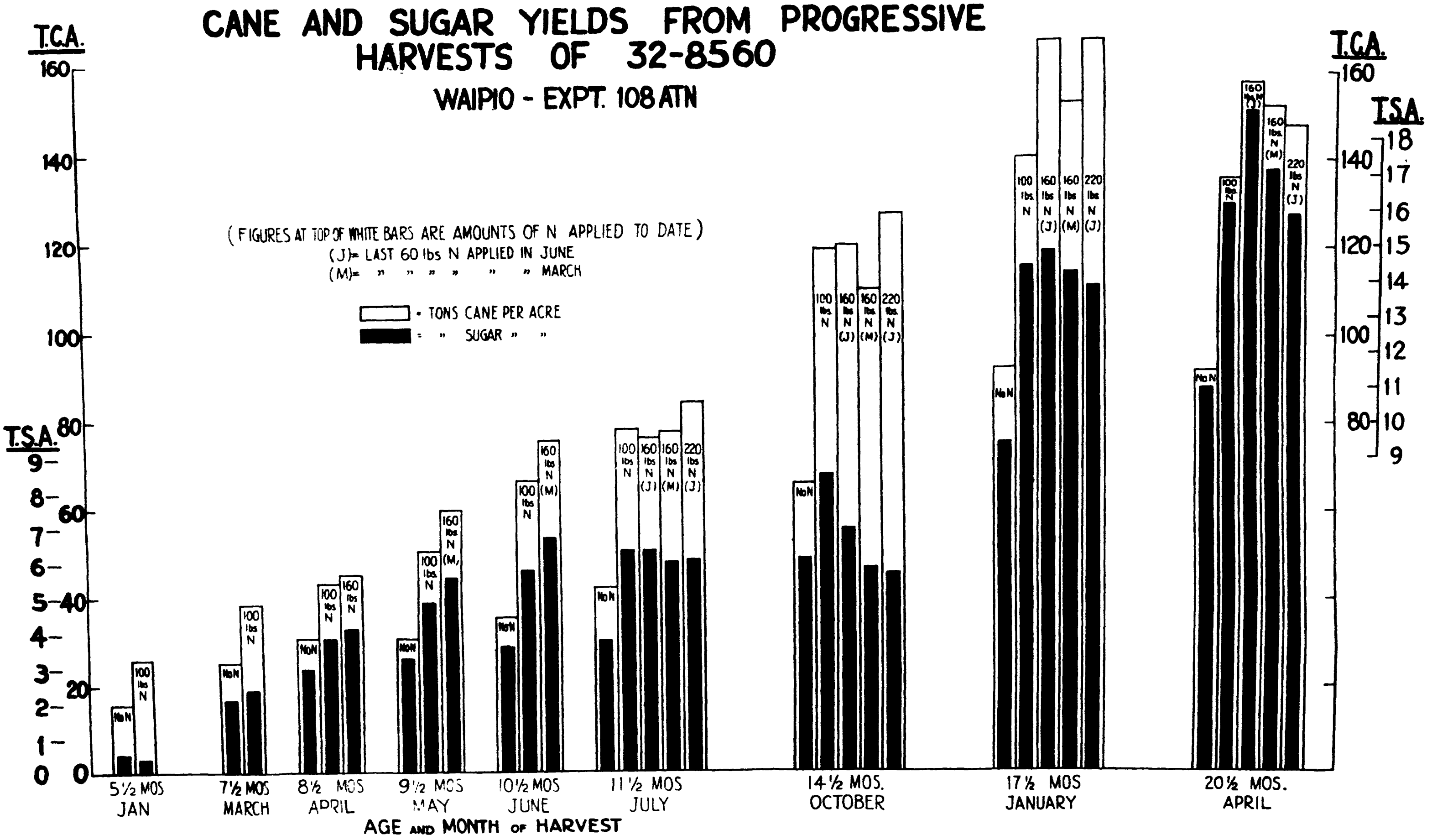
CANE AND SUGAR YIELDS FROM PROGRESSIVE HARVESTS OF 32-8560
WAIPIO - EXPT. 108 ATN
(FIGURES AT TOP OF WHITE BARS ARE AMOUNTS OF N APPLIED TO DATE)
(J)= LAST 60 lbs N APPLIED IN JUNE
(M)= " " " " " " MARCH
= TONS CANE PER ACRE
= " " SUGAR " "
T.C.A.
160
140
120
100
80
60
40
20
0
T.S.A.
9
8
7
6
5
4
3
2
1
0
T.S.A.
18
17
16
15
14
13
12
11
10
9
No N
100 lbs N
160 lbs N
160 lbs N (J)
160 lbs N (M)
220 lbs N (J)
5½ MOS JAN
7½ MOS MARCH
8½ MOS APRIL
9½ MOS MAY
10½ MOS JUNE
11½ MOS JULY
14½ MOS. OCTOBER
17½ MOS JANUARY
20½ MOS. APRIL
AGE AND MONTH OF HARVEST

Fig. 17

though treatments "C" and "D" had been given 60 pounds more nitrogen than "A" and "B" some 4 months previous.

At 14½ months we find the best yield of recoverable sugar from Treatment "A" which had only received a total of 100 pounds of nitrogen. Again, no significant differences were measured in the cane yields between the 4 nitrogen-fertilized groups. Hence, it is assumed, and later will be shown, that the differences in cane quality have been influenced by the nitrogen applications and thus are responsible for these sugar yields. It might appear that the zero nitrogen (X) plots have produced more sugar at this harvest than the higher nitrogen (D) plots, but this assumption can be challenged since it must be remembered that there were only 3 replicates of these "X" plots, and the experimental error at this October harvest was exceptionally high.

We find great increases in sugar yields from all treatments between 14½ and 17½ months, but Treatment "A" from its 100 pounds of nitrogen still appears to be the most profitable for this 32–8560 cane crop at Waipio, for there was apparently more cane tonnage to handle from the higher nitrogen treatments and no greater sugar yield recovered therefrom.

Finally, at the age of 20½ months, although we identified no differential nitrogen effects as statistically significant, there appears to have been less cane harvested from the 100-pound treatment than from those crops which received extra nitrogen, but at the same time it does not appear that Treatment "D" which had received 220 pounds of nitrogen had produced any more millable cane at 20½ months than plots which had been given only 160 pounds. As far as the recoverable sugar yields were concerned, those from the 220-pound nitrogen application, because of a poorer cane quality, were still under the yields obtained from the 100-pound application, but at the same time this 100-pound application for cane harvested at 20½ months was apparently inadequate since its sugar yield was less than that from the 160-pound applications.

These yield data, when set up as in Table III to show the increases or decreases made during specific growth periods, provide some interesting information and show the comparative effects of the differential nitrogen treatments.

TABLE III

AVERAGE* INCREASES OR DECREASES IN YIELDS OF TCA AND TSA

Growth period	Months	Age of crop (mos.)	TCA (net area)				
			X	A	B	C	D
1	Aug.–Jan.	0– 5½	+15.9	+22.9	+24.9	+26.5	+28.9
2	Jan.–Apr.	5½– 8½	+15.3	+19.0	+21.3	+18.7	+18.8
3	Apr.–July	8½–11½	+11.8	+38.0	+30.9	+32.4	+37.7
4	July-Oct.	11½–14½	+24.6	+39.8	+44.0	+33.6	+43.3
5	Oct.-Jan.	14½–17½	+24.4	+20.5	+45.1	+41.2	+37.3
6	Jan.–Apr.	17½–20½	— .8	— 3.9	— 8.3	— 1.2	—16.5

	TSA (net area)				
	X	A	B	C	D
1.....	+ .51	+ .21	+ .21	+ .24	+ .32
2.....	+2.50	+3.48	+3.95	+4.02	+3.96
3.....	+ .80	+2.77	+2.33	+1.77	+1.91
4.....	+2.41	+2.19	+ .53	— .10	— .40
5.....	+3.19	+5.76	+7.78	+8.31	+8.04
6.....	+1.66	+1.82	+4.05	+2.88	+2.02

* Average from 8 plots of Treatments A, B, C, and D, and from 3 plots of Treatment X.

Note: The horizontal bar (____) in the columns indicates that a nitrogen fertilizer application was made during the previous growth period.

During the first 2 growth periods, while all 32 fertilized plots were similarly enjoying the effect from 100 pounds of nitrogen, the recorded increases in tons cane per acre and tons sugar per acre were quite similar; such differences as are noted being only the chance effects from field variation.

The March applications of nitrogen to the C and D plots, which did not increase the cane yields over the A and B plots in the third and possibly the fourth growth-period, apparently did result in less recoverable sugar being stored up.

The effect on Treatment B from the June nitrogen application was an increase in cane tonnage over the previous period and also a sharp decline in the amount of sugar stored during the fourth period. A similar trend was found in the cane and sugar yields from Treatment D's nitrogen application in June.

The rather remarkable increases in the sugar yields during the fifth growth period when the crop was 14½ to 17½ months old are worthy of note and should be a warning to anyone who would "short crop" this cane variety. All treatments made their best accumulation of recoverable sugar during this 3-month growth stage—averages of 1.9, 2.6, 2.8, and 2.7 tons per acre per month being recorded for Treatments A, B, C, and D, respectively. Furthermore, it should be emphasized again that these increases were made simultaneously with increases in cane yields which, except for Treatment A, were not significantly less than gains made in previous growth periods.

During the sixth growth period the beneficial effects of the general practice of "drying-off" irrigated cane crops before harvesting are quite nicely verified. The last round of irrigation was given on January 21 and thereafter until the final harvest only 5.2 inches of rainfall were received. Apparently, cane growth was checked, moisture was lost from the crop, and green leaves were prematurely added to the trash. Certainly the net result was less cane tonnage to be harvested. Though not statistically significant, Treatment D, the high nitrogen treatment, appeared to take the greatest setback and lose more cane weight than lower nitrogen treatments; and Treatment B which was fertilized in June may have dropped off more than the "C" plots which were fertilized in March. At the same time all plots made increases in recoverable sugar, with the best gains being made by Treatments B and C; even the zero nitrogen "X" plots continued to store up sugar during this period at better than one-half ton per acre per month!

For those who like to compare relative performance or yields from cane lands on the basis of tons sugar-per-acre-per-month (TSAM) we have prepared Table IV. Certainly, until the age of 17½ months, Treatment A which had received only 100 pounds of nitrogen had made a creditable performance; and it would seem that the results from the 220-pound nitrogen application had not been as good as from lesser amounts for a crop which was harvested at 20½ months. What the result might have been if there had been harvests at more advanced ages is purely speculative.

TABLE IV

Treatment	Total lbs. N applied by June	Last 60-lbs. N applied	Tons sugar-per-acre-per-month (net area) July at 11½ mos.	October at 14½ mos.	January at 17½ mos.	April at 20½ mos.
A	100	November	.56	.60	.82	.79
B	160	June	.56	.48	.85	.92
C	160	March	.52	.41	.81	.84
D	220	June	.54	.40	.79	.77

(*c*) *Relation Between Recoverable Sugar and Total Sucrose (Fig. 18):* In the sugar business there is no advantage in having the crop store up a lot of sucrose which cannot be commercially recovered, and so we are interested in the effect of nitrogen fertilizer on the amounts of total sucrose which are recoverable. Several separate references have already been made to these measurements but in Fig. 18 they are brought together to show better their relationships. Thus we see that although the total sucrose increased between July and October in all treatments, the recoverable sugars in the higher nitrogen treatments did not keep pace with them during the season of maximum temperatures and sunshine, and there was a

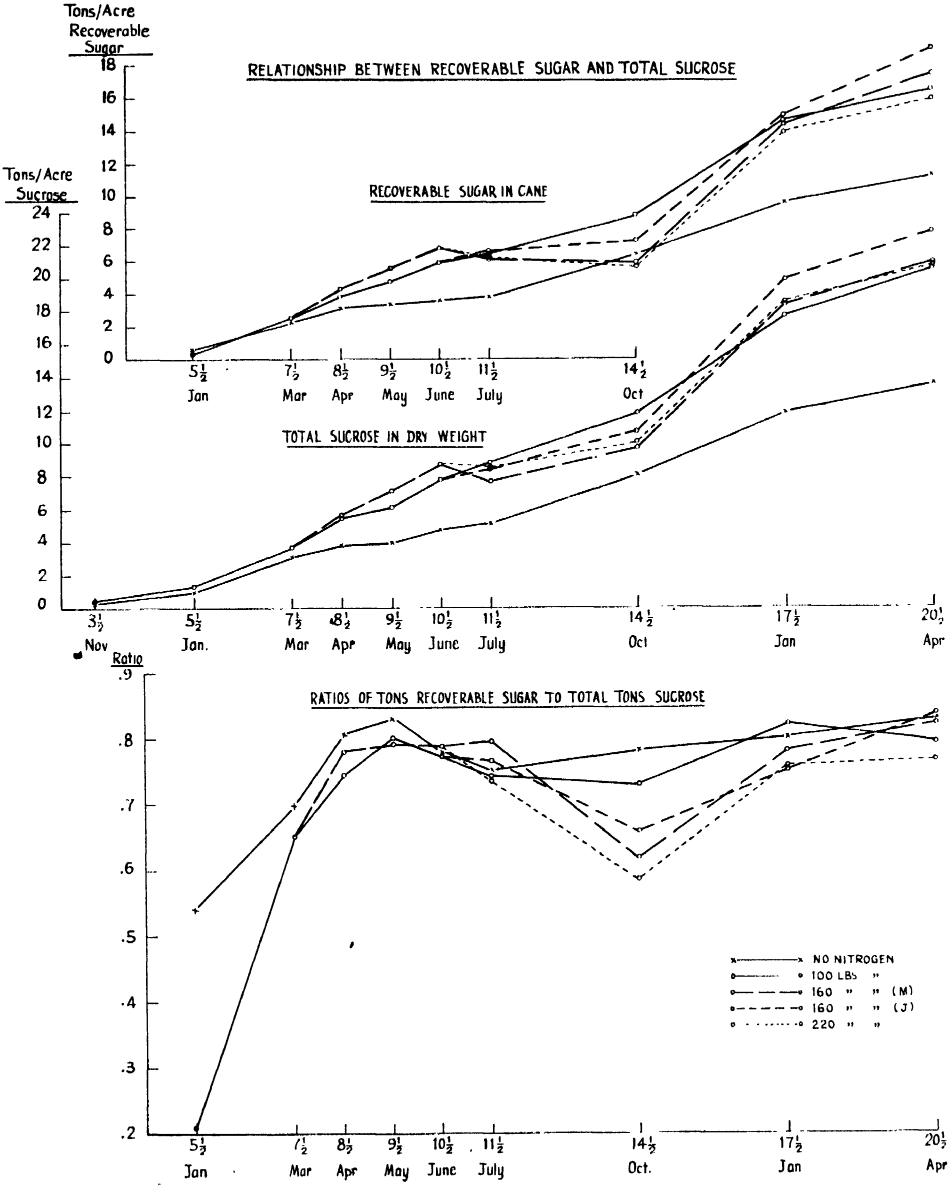

Fig. 18

slight carry-over of these divergent responses to January. At other seasons the ratios of recoverable sugars to total sucrose were more nearly parallel.

Perhaps these recovery figures indicate that the so-called "harmful" effect from too much nitrogen is especially an effect on the percentage of total sucrose stored in the crop which cannot be commercially recovered at harvest. If this is so, then it gives emphasis to our earlier contention that our guidance for more intelligent nitrogen fertilization must be such as to enable us to avoid the application of an excessive amount of this nutrient.

8. On Cane Quality (Fig. 19) :

Cane quality in this study has been recorded as "yield per cent cane" or Y%C, this term being used to indicate the unit yield of recoverable commercial sugar per 100 units of cane milled. Basic data for this calculation came from the corrected* Brix and pol analyses of Waipio mill crusher juices from one half of the entire sample of millable canes harvested from each plot.

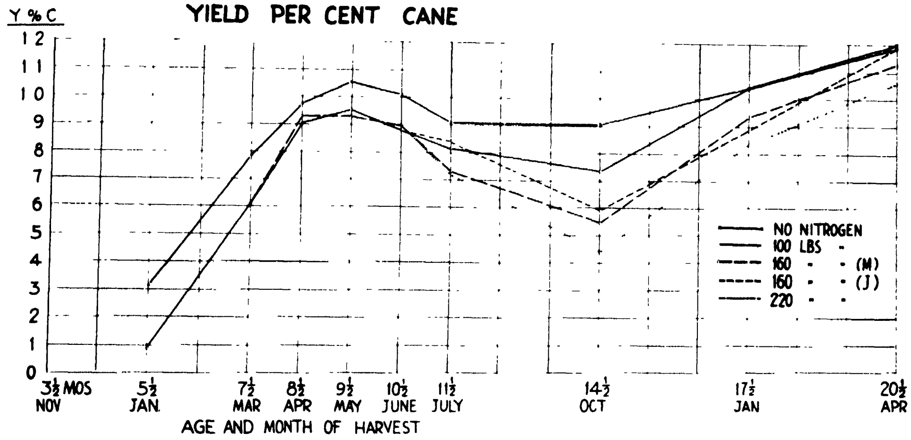

Fig. 19

The effect of the nitrogen differentials upon the yield per cent cane is quite clear and consistent, and we find fewer pounds of recoverable sugar per 100 pounds of cane to have resulted from each increase in the total nitrogen applications.

There was especially low Y%C in October from the plots which had received over 100 pounds of nitrogen, but an excellent "comeback" in January indicates that an October harvest at 14½ months would have been a serious mistake.

A special attempt was made to find the reason for the poor cane quality from the October samples. Since the effect was greatest on Treatment D, a new collection of cane samples was made from a series of "D" plots in October. These were separated into 2 easily distinguishable groups: (1) primary and secondary stalks which had originated in 1940, and (2) suckers with at least 6 feet of stalk which had originated early in 1941. This second group was found by actual count to make up 31 per cent of the total number of millable stalks, and 20 per cent of the total weight of millable cane came therefrom. Crusher juice analyses from the 2 groups showed an average Y%C of 6.5 from the older stalks and of 4.7 from the millable sections of the sucker growth. A follow-up on this special study, made from the same series of plots in February, showed that millable suckers then made up 28 per cent of the total number and again 20 per cent of the total weight, but that the Y%C figures were now nearly equal, *i.e.*, at 9.8 for the older stalks and 9.7 for the suckers. Thus it is apparent that there is an optimum time to harvest a cane crop which has a stalk population with 28 to 30 per cent suckers carrying millable cane to the mill.

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* Waipio Cuban A mill samples corrected to equivalents for Oahu Sugar Co.'s mill crusher juices.

9. *On the Recovery of Plant Nutrients in the Total Dry Weight**:

Due to obvious practical difficulties in separating and collecting the trash and roots from each sampling station, we do not have as complete a picture of the nutrient recovery as we would wish; hence our figures are low. Both trash and roots make up quite a considerable amount of the total dry matter produced by a sugar cane crop. Calculations made by Moir (4) from work of Stewart and Wolters show the following approximate proportions of the various plant parts from H 109 cane grown at Waipahu:

AVERAGE MAKE-UP OF TOTAL DRY WEIGHT PRODUCED

Age	Top	Trash	Roots	Stalks
12 mos.	15%	14%	5%	66%
17 mos.	10%	17%	4%	69%
24 mos.	5%	24%	2%	69%

From data reported by Stewart (5) in which H 109 trash, tops, and stalks (but no roots) were weighed and analyzed, we have calculated that 15 per cent of the total nitrogen taken up by the plants (exclusive of roots) was found in the trash at 12 months, 22 per cent at 17 months, and 33 per cent at 24 months. From similar data secured from Waipio Experiment E at 12, 18, and 21 months, we note that 19 per cent, 28 per cent, and 25 per cent of the total nitrogen was found in the trash.

Pot studies (Project A 105—No. 161) of 4 cane varieties harvested at 12 months have shown the following percentages of total nitrogen recovered which were found in the roots only: 24 per cent from 31-1389, 28 per cent from H 109, 29 per cent from 32-1063, and 30 per cent from 32-8560. Unfortunately trash was not kept separate from tops for chemical analyses made in this study, but we have these percentages of the total nitrogen recovered which were found in the combined trash and tops at 12 months: 44 per cent from 32-8560, 48 per cent from 32-1063, 48 per cent from 31-1389, and 49 per cent from H 109.

These scattered data should tend to support our contention that our figures for nutrient recovery must be considered lower than the actual total uptake by the crop.

(*a*) *Nitrogen (Fig. 20)*: In spite of the fact that our nitrogen recovery figures are incomplete, since they do not include the nitrogen in the trash or roots, they do provide us with a reliable indication of relative effects from the different nitrogen treatments, for statistically significant effects of treatment were found at each preharvest after the different amounts of nitrogen had been applied.

Of special interest is the fact that the crop grown without nitrogen fertilization on the "X" plots was able to pick up between 50 and 60 pounds of nitrogen per acre during its first year of growth, and that an additional amount was secured during its second year. This must have been a contribution from the natural supply in the soil, and this is enlightening since the total nitrogen in the Waipio soil is relatively low.

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* **Except trash and roots.**

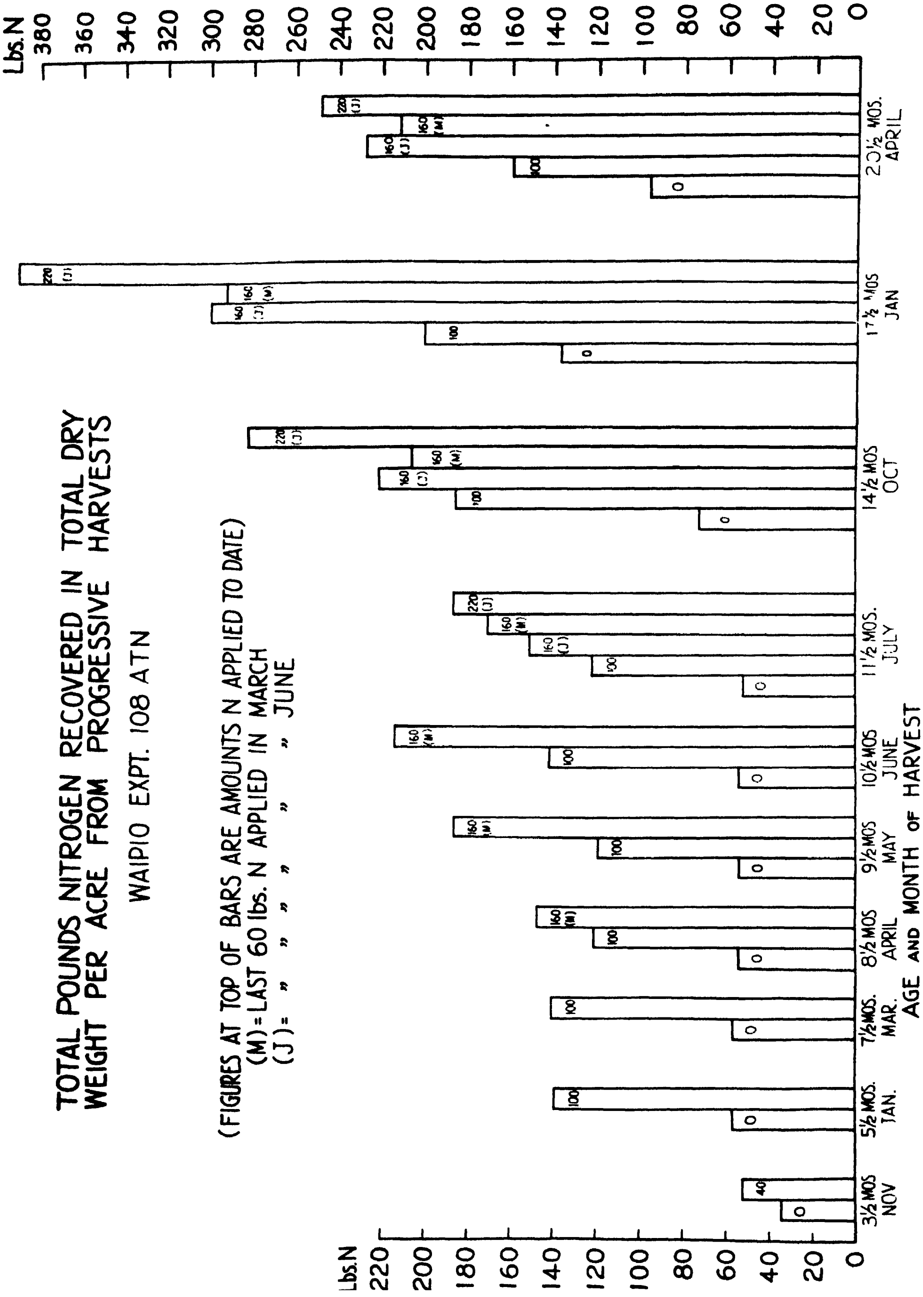

Fig. 20

At the age of 3½ months, the fertilized cane had been able to pick up only 55 pounds of nitrogen per acre—only 20 pounds more than the crop which received no nitrogen, and reference to our observational notes and data shows that neither visible nor significantly measurable differences were noted at this time between the fertilized and non-fertilized plots. However, during the next 2 months when marked differences became apparent—and these were winter months too, the fertilized crop made a fairly complete absorption of the nitrogen which had been applied.

Definite uptake of the 60-pound nitrogen application made in March is seen in its efficient recovery in May and June.

The recovery figures for July are "out of line"; the reason is only speculative but it may be tied up with losses of nitrogen contained in the trash which was abundant at this harvest. Hence the recovery in the October samples and again in the January samples best reflects the nitrogen fertilizer effects after the June applications, and in both of these instances we must recognize the amount contributed by the soil, as indicated in the recovery by the zero nitrogen plots.

At the final preharvest in April, all treatments had lost nitrogen. Again the reason is believed to be associated with the trash losses, and in this case, because the crop was being artificially dried-off, many immature leaves which had not completed their normal life cycle and translocated their surplus nitrogen were dropped to the trash blanket and so their nitrogen was not found in the cane samples. This loss of nitrogen during the last 3 months was (1) greatest from the cane in Treatment D which had received the high total nitrogen application, (2) least from Treatments X (no nitrogen) and A (100 pounds nitrogen), and (3) intermediate from those plots which received the 160-pound applications.

(*b*) *Phosphate and Potash (Fig. 21):* The actual recoveries of phosphate and potash per acre of crop harvested are shown in Fig. 21. In both cases the only significant differences between the 4 nitrogen treatments occurred in the May and June preharvests and were most likely the result of the March application of ammonium sulphate; the effect was an increase in the recoveries of both nutrients following this application.

The actual amounts of phosphate found in the crop during its first year of growth were under 80 pounds per acre. The maximum amounts were found in the crop harvested at 17½ months; these were under 175 pounds, and when considered in relation to the millable cane tonnage harvested make it appear that if the crop can get hold of one pound of P_2O_5 for each ton of millable stalks it will produce, this amount should be adequate, for this cane variety.

The large potash recoveries are at first glance somewhat staggering but it must be remembered that they include the potash in the green leaves and tops as well as in the stalks. The actual amounts average about 3 times the amounts of nitrogen that were found in the dry weights at consecutive harvests, and about seven times the amounts of phosphate.

The uptake of potash was in many respects similar to that of nitrogen, *i.e.*, it continued to be fairly uniform after the crop was well under way, although the July drop in nitrogen was not paralleled in potash. Like both nitrogen and phosphate, the potash recoveries in the final harvest at 20½ months were less than those found at 17½ months, and the greatest decreases were in Treatment D which had received the largest amount of nitrogen, and least from Treatments X and A. The best crops took up approximately 6 pounds of potash for each ton of millable stalks they produced.

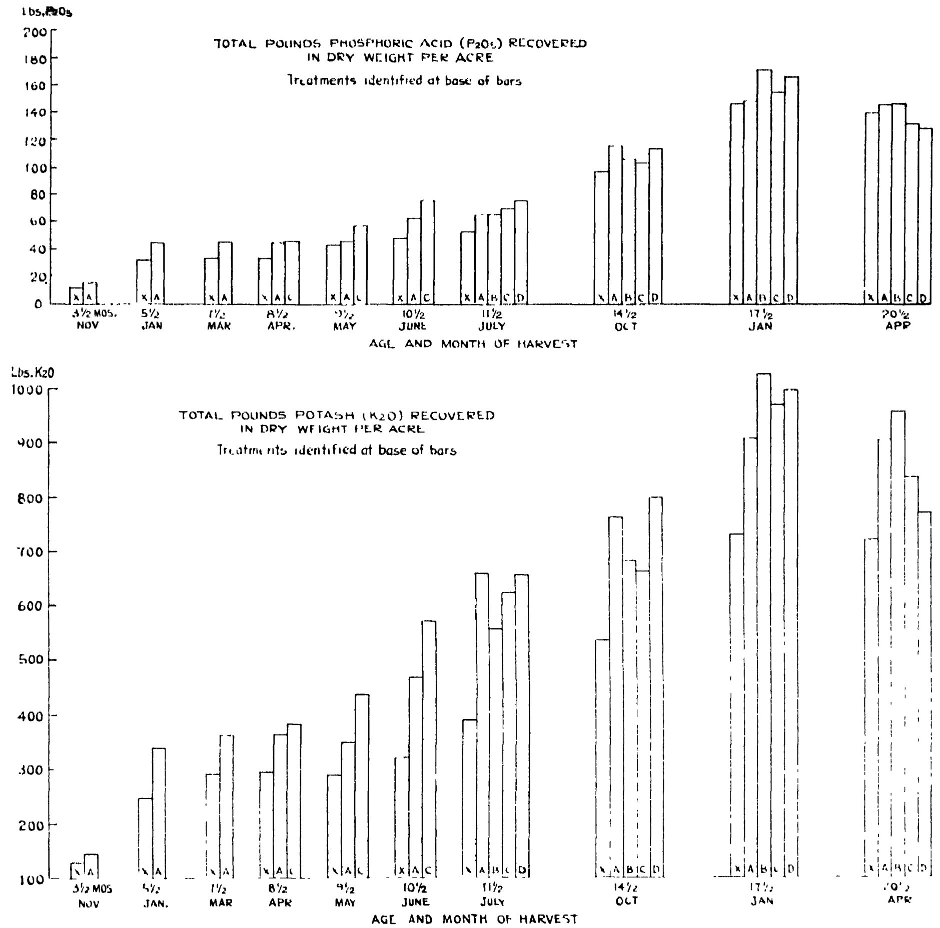

Fig. 21

NITROGEN CORRELATION

Between Per Cent Nitrogen in Leaf-punch Samples and Per Cent Nitrogen in Total Dry Weight:

There may be an interesting story from a study made of the correlation between the percentage of nitrogen in the leaf-punch samples and the corresponding percentage in the total dry weight. This study indicates certain practical limitations to the usefulness of leaf-punch or other percentage data, and may also be why we do not yet feel as confident about relying upon plant composition figures to indicate nutrient needs for sugar cane as some workers do for other crops. As previously mentioned our big problem is to find out whether our cane crop will need *more nitrogen* at a rather specific time and *after it has already been given a moderate amount;* thus we will seldom have cane with the low nitrogen content which is found in cane crops that have received little or no nitrogen fertilizer at all. This makes it exceedingly difficult for percentage figures for nitrogen in some portion of a cane crop to be sufficiently different as to be positively identified as high or low at a specific time, and both the age of the crop and its associated tonnage can further complicate the interpretation.

In Table V it will be noted that the effect of age, which in this case is inseparably combined with total dry weight, had an influence on the percentage composition of both leaf and total dry weight, for in spite of the fact that more nitrogen was applied to certain plots in March and again in June, the true average percentages found in all plots continued to decrease.

TABLE V

PER CENT NITROGEN IN LEAF-PUNCH AND IN TOTAL DRY WEIGHT AND ITS CORRELATION

		True average—all plots		Correlation coefficient (r)	
Age	Month of sampling	Per cent N in leaf	Per cent N in total dry wt.	With all 35 plots	Without 3 zero N plots
7½	March	1.74	.515	+.76∓.07	+.22∓.17
8½	April	1.53	.423	+.64∓.10	+.26∓.16
9½	May	1.43	.401	+.57∓.11	+.25∓.16
10½	June	1.37	.368	+.74∓.08	+.22∓.17
11½	July	1.38	.312	+.79∓.06	+.31∓.16

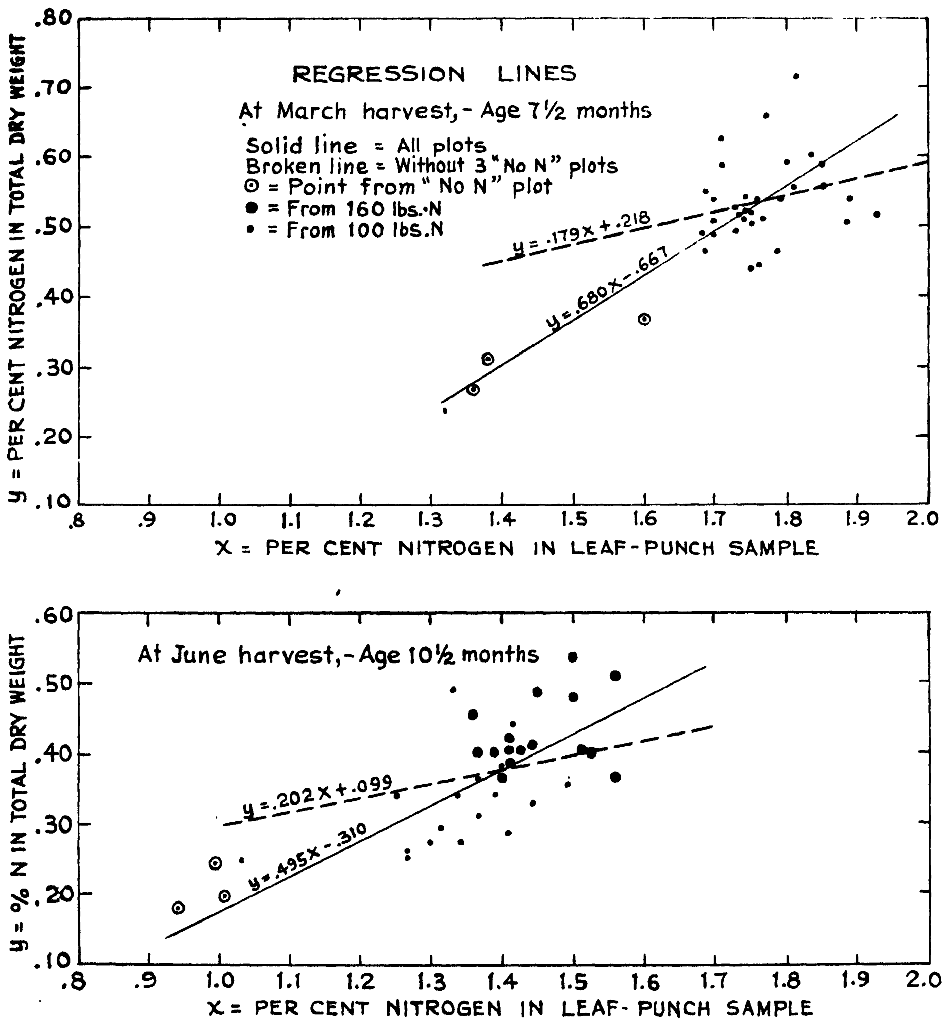

Fig. 22

The percent N in the leaf-punch samples was positively correlated with the per cent N in the total dry weight when the difference in the amount applied was a difference between zero and 100 pounds, or between zero and 160 pounds. But the dominant influence of the zero nitrogen plots is seen by the fact that when only 3 zero nitrogen plots are omitted from the correlation study, the remaining 32 plots fail to show significant correlation coefficients, in spite of the fact that different nitrogen treatments are involved after the March harvest. This is nicely shown by the regression lines in Fig. 22; without the 3 points from the zero nitrogen plots, the prediction of per cent nitrogen in the total dry weight on the basis of the percentage found in the leaf-punch samples would be quite unreliable.

WEATHER RELATIONSHIPS

Among other things needed to make our search for guidance in nitrogen fertilization more fully complete are studies of nitrogen utilization under different conditions of sunlight and temperature. Unfortunately our present investigation did not include these variables. Hence the best we can do here is to record the basic weather measurements made at Waipio while our crop was growing, and thereafter to study certain relationships between them and the response made especially by Treatment B which eventually proved the most efficient sugar producer. Therefore the basic data have been prepared by dividing the crop into six growth periods, each except the first being periods of 3 months, and recording the yields and the corresponding weather measurements during these 6 periods:

TABLE VI

BASIC YIELD AND WEATHER DATA

			(1) Increase in yields—tons/acre—avg. of 8 "B" plots				
Growth period	Dates	Age (mos.)	Green wt.	Dry wt.	Total sugars	TCA	TSA
1	8/1 to 1/13	0- 5½	44.18	8.86	2.088	25.78	.25
2	1/14 to 4/14	5½- 8½	16.20	6.09	4.063	18.28	3.67
3	4/15 to 7/14	8½-11½	36.96	9.41	3.728	33.06	2.57
4	7/15 to 10/13	11½-14½	45.51	8.96	3.334	44.00	.53
5	10/14 to 1/12	14½-17½	45.00	14.91	9.124	45.14	7.78
6*	1/13 to 4/20	17½-20½	—14.18	1.80	2.249	—8.27	4.05

(2)	Weather measurements						Avg. wind velocity m.p.h.
	Gram calories	Hours of sunshine	Day-degrees	Avg. temperature Min.	Avg. temperature Max.	Range in temperature	
1	73,608	1,139	2,426	67.2°	84.0°	16.8°	5.65
2	41,957	742	978	61.20°	80.2°	19.0°	6.22
3	54,454	829	1,457	65.7°	86.0°	20.3°	6.01
4	48,666	722	1,692	68.9°	88.6°	19.7°	5.60
5	36,068	449	1,203	63.0°	83.2°	20.2°	5.25
6	46,327	348	1,220	61.1°	82.4°	21.3°	6.06

* Drying off.

TABLE VII

SUNLIGHT AND TEMPERATURE UTILIZATION (BY TREATMENT B)

Growth period	Tons total green wt. per acre			Tons total dry wt. per acre			Tons total sugars per acre		
	per 1000 grams cal.	per 100 hours sun.	per 1000 day-degrees	per 1000 grams cal.	per 100 hours sun.	per 1000 day-degrees	per 1000 grams cal.	per 100 hours sun.	per 1000 day-degrees
1	.600	3.878	18.211	.120	.778	3.652	.028	.183	.861
2	.386	2.183	16.564	.145	.821	6.227	.097	.548	4.154
3	.679	4.458	25.367	.173	1.135	6.458	.068	.450	2.559
4	.935	6.303	26.897	.184	1.241	5.296	.069	.462	1.970
5	1.248	10.022	37.406	.413	3.320	12.394	.253	2.032	7.584
6	(Loss)	(Loss)	(Loss)	.039	.517	1.475	.049	.646	1.843

Growth period	Tons millable cane per acre			Tons comml. sugars per acre		
	per 1000 grams cal.	per 100 hours sun.	per 1000 day-degrees	per 1000 grams cal.	per 100 hours sun.	per 1000 day-degrees
1	.350	2.263	10.627	.003	.022	.103
2	.436	2.464	18.691	.087	.495	3.753
3	.607	3.988	22.690	.047	.310	1.764
4	.904	6.094	26.005	.011	.073	.313
5	1.252	10.053	37.523	.216	1.733	6.467
6	(Loss)	(Loss)	(Loss)	.087	1.163	3.320

From Table VI we have prepared Table VII to show the relative efficiency of temperature and sunlight received during the 6 growth periods selected. Though perhaps somewhat foreign to the immediate objective of our nitrogen study, we cannot let these data pass without a short comment.

Sunlight energy, as measured in gram calories on a pyroheliometer, apparently had a very different degree of efficiency during these 6 growth periods, being particularly effective on adequately fertilized cane between October and January when the crop was 14½ to 17½ months old; this same superiority was also found for the unit hours of sunshine and also for day-degrees, both of which with a few exceptions show a good relationship with the gram calories. Whether this superior utilization of sunlight energy in the fifth growth period is the effect of age or time of year or their interaction, only further research can tell, and just whether this effect could be changed by nitrogen applications will remain an open question until a more extensive and comprehensive study is made.

Some Interesting Ratios

We have searched the data obtained in this study for such enlightening relationships as may be found, and several of these have been recorded hereafter as specific ratios.

1. Ratio of Per Cent Total Sugars to Per Cent Nitrogen in Total Dry Weight:

First we made a study of the relationship between the total nitrogen and sugar percentages in the total dry matter harvested. We have one group of 32 analyses made from cane 3½ months old that was grown on plots which had received 40 pounds of nitrogen two months previously which shows a total sugar concentration that averages only 10 times the concentration of nitrogen at this age.

A second and a third group from these same 32 plots, harvested in January and March after all had been supplied with 100 pounds of nitrogen per acre, show average ratios of per cent sugars to per cent nitrogen of 29 to 1 and of 65 to 1, respectively. Further harvests in April, May, and June from 16 of these same plots which had still received only 100 pounds of nitrogen fertilizer showed that these same ratios had been increased to 102, 115, and 124 respectively.

A more specific comparison of the ratios of per cent sugar to per cent nitrogen from the cane of 8 replicates of Treatments A and B, which had been similarly fertilized until after the June preharvests at 10½ months, reveals no significant differences:

RATIOS OF PER CENT SUGARS TO PER CENT NITROGEN IN TOTAL DRY WEIGHT

Treatment	At 3½ mos.	At 5½ mos.	At 7½ mos.	At 8½ mos.	At 9½ mos.	At 10½ mos.
A	9.7	28.3	63.1	103.2	119.6	123.5
B	9.3	28.9	63.0	101.4	111.5	124.5

Since Treatment B finally outyielded Treatment A, it would appear from these data that these high ratios at 10½ months indicated a high carbohydrates—low nitrogen status which was not optimum at this time, and the application of additional nitrogen was called for.

A similar comparison of Treatment C and D shows the following:

RATIO OF PER CENT SUGARS TO PER CENT NITROGEN IN TOTAL DRY WEIGHT

Treatment	At 3½ mos.	At 5½ mos.	At 7½ mos.	At 8½ mos.	At 9½ mos.	At 10½ mos.
C	10.3	30.5	68.3	88.2	83.4	93.6
D	11.0	30.1	67.3	81.6	88.4	96.5

At 7½ months (in March), these ratios were not significantly different from those for Treatments A and B. However, the March nitrogen applications to Treatments C and D were effective in lowering the per cent sugar to per cent nitrogen ratios, and at 10½ months in June they were considerably below the corresponding ratios for the A and B plots. Hence it would appear that a ratio of per cent sugar to per cent nitrogen of about 95, if found in the crop in June at the age of 10½ months, may indicate a desirable carbohydrate-nitrogen status at this time, since when still more nitrogen fertilizer was given to Treatment D in June, it was eventually shown to be an unnecessary application.

2. *Ratio of Pounds Nitrogen Per Acre Recovered in Crop to Tons Millable Cane Harvested:*

A figure for the number of pounds of nitrogen taken up by the crop with each ton of millable cane harvested has been a favorite measurement sought by some sugar men as a guide to the total amount which they should supply for any estimated tonnage. Thus the following summary was prepared:

POUNDS NITROGEN RECOVERED FOR EACH TON OF MILLABLE CANE HARVESTED

Treatment	At 14½ mos.	At 17½ mos.	At 20½ mos.
X	1.1	1.5	1.1
A	1.6	1.4	1.2
B	1.9	1.8	1.4
C	1.9	1.9	1.4
D	2.2	2.4	1.7

Again it must be pointed out (1) that these data do not include that nitrogen which is still unaccounted for in the roots and trash, and (2) that the nitrogen recovery at 20½ months was undoubtedly influenced by the loss of prematurely dehissed leaves during the drying-off period. But perhaps we can interpret the figures liberally as showing that we need not plan total nitrogen applications for 32–8560 crops any greater than an amount which is 2 pounds for each ton of millable cane expected. By the same reasoning, this allowance should probably not be less than 1½ pounds of nitrogen for each expected ton of this cane variety.

3. *Ratio of Per Cent Reducing Sugars to Per Cent Sucrose:*

The influence of the different nitrogen treatments on the ratios of reducing sugars to sucrose is seen in the following data:

RATIO OF PER CENT REDUCING SUGARS TO PER CENT SUCROSE

Treatment	March	April	May	June	July	Oct.	Jan.	April
X	.10	.08	.06	.06	.08	.06	.04	.02
A	.21	.11	.10	.12	.11	.14	.06	.03
B	...	...	...	...	.12	.20	.08	.04
C	...	.11	.11	.12	.15	.20	.07	.04
D	...	...	...	...	.15	.26	.09	.05

The increased ratios from the nitrogen-fertilized cane as found in October and the low ratios in January and April offer another way of indicating the changes in cane quality which were measured at these preharvests.

4. *Ratio of Tons Total Sugars to Tons Total Dry Weight:*

There were negligible differences in each successive harvest, in the ratio of total sugars to total dry weight, which were the effect from the different amounts of nitrogen applied. Furthermore, there was but little change in this ratio from successive harvests between March and October. Apparently the total sugar being manufactured in the cane plant kept in step with the total dry weight being produced during the first two-thirds of the growth period, but after this time the total sugars accumulated somewhat faster than the total dry weight. Such is our interpretation of the following data:

RATIO OF TOTAL SUGARS TO TOTAL DRY WEIGHT

Treatment	Nov.	Jan.	March	April	May	June	July	Oct.	Jan.	April
X	.12	.24	.38	.39	.40	.40	.40	.41	.46	.48
A	.11	.24	.35	.41	.41	.41	.41	.41	.46	.50
B	...	...	...	...	...	...	.41	.41	.46	.49
C	...	...	...	.41	.41	.41	.39	.39	.45	.49
D	...	...	...	...	...	...	.39	.38	.45	.51

5. *Ratio of Tons Reducing Sugars to Tons Total Dry Weight:*

This ratio of reducing sugars to the total dry weight was definitely affected when the cane crop was fertilized with nitrogen. Little change in this ratio occurred from the March fertilization within the subsequent 3 months, but at the time of the last 4 preharvests, the extra nitrogen given to Treatment C had increased its reducing sugars to dry weight ratio over Treatment A. Similarly the June applications of fertilizers were responsible for increases in this ratio. These conclusions are drawn from the following data:

RATIOS OF REDUCING SUGARS TO TOTAL DRY WEIGHT

Treatment	Nov.	Jan.	March	April	May	June	July	Oct.	Jan.	April
X	.050	.068	.033	.028	.020	.022	.029	.022	.018	.011
A	.060	.091	.058	.040	.037	.042	.038	.049	.024	.012
B	....	....	....	....	....	....	.041	.062	.034	.016
C	....	....	....	.038	.038	.043	.049	.062	.027	.016
D	....	....	....	....	....	....	.049	.073	.038	.023

6. *Ratio of Tons Sucrose to Tons Dry Weight:*

To complete the picture, it will be seen from the following table that the nitrogen treatments which increased the ratio of reducing sugars to dry weight have at the same time decreased the ratio of sucrose to dry weight. Finally we note that at the last preharvest, differences in these sucrose to dry weight ratios from the fertilized canes, which had previously existed, were almost entirely ironed out.

RATIO OF SUCROSE TO TOTAL DRY WEIGHT

Treatment	Nov.	Jan.	March	April	May	June	July	Oct.	Jan.	April
X	.071	.164	.325	.340	.358	.355	.351	.366	.422	.446
A	.045	.137	.275	.353	.356	.354	.350	.343	.414	.466
B	....	....	....	....	....	....	.346	.318	.408	.451
C	....	....	....	.345	.350	.347	.323	.311	.405	.454
D	....	....	....	....	....	....	.326	.294	.390	.461

DISCUSSION

Many of the data presented herein have already been adequately discussed but perhaps certain aspects should now be brought together to show just where our nitrogen problem stands at the moment.

Since soil analyses for both available and total nitrogen, which are made on samples taken before or subsequent to planting, apparently offer but little promise for specific guidance in nitrogen fertilization after the crop is well under way, we have turned to the cane crop for our answer.

Specific effects from differences in nitrogen applications—some desirable, others not so desirable—have been measured on the cane crop and sugar yields, and certain analyses have been found associated with these effects. An optimum recoverable sugar yield from 32–8560 plant cane harvested at 20½ months has been identified as the most likely result of known differences in nitrogen fertilization. Hence we may postulate that various measurement levels, which were associated with specific nitrogen treatments at the time of the March and the June fertilizations, offer an index of future nitrogen needs which we are seeking for the immediate crop under consideration. So we would point out what appear to have been optimum levels for certain measurements—levels above which an additional 60 pounds of nitrogen in our study was later proved uneconomical, and levels below which another 60 pounds of nitrogen was quite profitable. At the same time we emphasize that such levels as we found when the crop was only 7½ and 10½ months old were probably subjected to many separate influences and interactions which affected the final sugar recoveries 10 or 12 months later, so, much additional work will need to be done before these levels are sufficiently verified and established for the planter's guidance.

When our crop of 32–8560 cane had already been supplied with 100 pounds of nitrogen and had made normal development at 7½ months, we found that an additional 60 pounds of nitrogen were profitable for a 21-month crop under these conditions: (*a*) when only .53 per cent nitrogen was found in a sample of the total dry weight, (*b*) when the nitrogen in the leaf-punch samples was as low as 1.77 per cent, or (*c*) when the crusher juice from the stalks carried only .030 per cent nitrogen. Upper limits for cane at this stage of growth have not as yet been suggested by our studies.

When the crop was 10½ months old, we had what may be a suggestion for both the upper and the lower limits for these nitrogen measurements, but they are so close together that a highly accurate cane sampling technique is going to be needed if they are to be measured with confidence. Thus (*a*) with only .33 per cent nitrogen in the total dry weight at 10½ months, an extra 60-pound application was justified, but when .43 per cent nitrogen was found at this age, there was apparently no need for another nitrogen application; (*b*) with a leaf-nitrogen index at 1.36 per cent, another 60 pounds of nitrogen was called for but when this index was at 1.46 per cent, further nitrogen was found to be unnecessary; and (*c*) lower and upper limits of .018 per cent and .030 per cent respectively in the crusher juice at this age probably represented deficiencies and sufficiencies of nitrogen for another year of growth and sugar accumulation by this crop. Or perhaps the guide we want is indicated by the ratio of the per cent total sugars to per cent total nitrogen that was found in the dry weight at 10½ months; a ratio of approximately 125 to 1 indicated a need for additional nitrogen, whereas no economic increase in sugar yield was made from additional nitrogen when this ratio was 95 to 1.

Finally, we reiterate, that attempts to secure reliable and practical guidance in the use of nitrogen fertilizers, from indices of concentrations or of total amounts of nitrogen found in samples of sugar cane soils and crops, can be successful only if analyses and measurements are made from adequately replicated and truly representative samples. Furthermore, success in the interpretation of such data will await verification of their relationships with the most probable yields of recoverable sugar associated therewith.

The work is being continued. The ratoon crop is well under way and the plan of procedure will be quite similar to that of this plant crop. With certain levels of plant nitrogen content in mind, we seek their verification and further knowledge of their associations. Concurrently, a somewhat similar but more extensive study —with provision for more differentials in the applied nitrogen fertilizer—is underway at Makiki (Expt. 20 AxTN).

ACKNOWLEDGMENTS

The writer has had the privilege of compiling, studying, and trying to interpret the measurement and analytical data which were obtained by the staffs of the several departments which cooperated in this nitrogen study. The crop was grown at Waipio under the careful supervision of F. C. Denison, B. K. Nishimoto and their assistants. Credit for the tremendous amount of work connected with obtaining and preparing the soil and the cane samples must go to R. E. Doty, L. R. Smith, A. H. Cornelison, A. Y. Ching, and their assistants (Y. Yamasaki and Y. Ikawa). The many soil analyses, the analyses of the nutrients in the crop samples and the

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APPENDIX

Containing Summaries of Data and Statistical Measurements Thereof

(Measurements from the 3 "X" plots were not included in the statistical computations.)

TABLE 1

TOTAL GREEN WEIGHT—TONS PER ACRE

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	11.22	27.70	38.63	42.35	40.98	46.51	55.21	80.15	103.31	103.17
A	14.35	44.18	57.84	60.38	66.28	84.38	98.48	139.48	158.69	148.70
B	.....	......	......	......	......	......	97.34	142.85	187.85	173.67
C	.....	......	......	62.67	79.43	96.75	99.14	131.39	171.17	164.58
D	.....	......	......	......	......	......	107.66	150.88	188.02	163.59
S.D.*	3.22	8.04	7.61	11.45	13.26	16.92	16.76	33.61	24.94	28.84
C.V.*	22.5	18.2	13.2	18.6	18.2	18.7	16.6	23.8	14.1	17.7
M.d.r.*	.....	......	......	ns	9.7	ns	ns	ns	ns	ns

TABLE 2

PER CENT TOPS IN TOTAL GREEN WEIGHT

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	.....	42.71	30.35	26.35	23.73	22.32	22.01	15.66	11.63	11.70
A	.....	40.97	31.71	26.88	23.13	20.08	18.92	15.17	11.79	8.46
B	.....	......	......	......	......	......	20.81	15.47	11.43	9.01
C	.....	......	......	25.94	24.53	21.63	21.75	14.64	11.04	8.26
D	.....	......	......	......	......	......	20.80	15.66	11.53	8.55
S.D.*	.....	2.01	2.48	2.50	1.89	2.03	1.56	1.59	1.49	1.33
C.V.*	.....	4.9	7.8	9.5	7.9	9.7	7.6	10.6	13.0	15.5
M.d.r.*	.....	......	......	ns	1.39	1.49	1.62	ns	ns	ns

* S.D. = Standard Deviation.
C.V. = Coefficient of variation.
M.d.r. = Minimum difference required for significance between Treatment A, B, C, and D only.
ns = Treatment effect not significant.

TABLE 3

PER CENT MOISTURE IN TOTAL GREEN WEIGHT

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	81.64	79.16	75.98	74.01	73.16	72.14	73.96	72.82	72.79	70.86
A	82.20	79.94	76.93	75.12	74.41	74.28	74.75	75.44	73.23	70.61
B	.....	......	......	......	......	......	74.96	76.67	74.42	71.29
C	.....	......	......	74.79	74.75	74.29	76.26	76.59	73.79	72.34
D	.....	......	......	......	......	......	76.27	77.91	75.03	72.70
S.D.	.....	.71	1.01	1.37	1.02	1.23	1.39	1.19	1.28	1.10
C.V.	.....	.09	1.3	1.8	1.4	1.7	1.8	1.6	1.7	1.5
M.d.r.	.....	......	......	ns	ns	ns	1.44	1.25	ns	1.14

TABLE 4

TOTAL DRY WEIGHT—TONS PER ACRE

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	2.06	5.77	9.28	10.94	11.00	12.88	14.37	21.79	27.71	29.94
A	2.55	8.86	13.37	14.95	16.96	21.68	24.81	34.31	42.33	43.77
B	.....	......	......	......	......	......	24.36	33.32	48.23	50.03
C	.....	......	......	15.83	20.11	24.79	23.48	30.79	44.80	45.59
D	.....	......	......	......	......	......	25.57	33.72	46.87	44.82
S.D.	.54	1.62	1.91	3.01	3.57	4.11	4.12	9.06	6.80	9.13
C.V.	21.2	18.3	14.3	19.6	19.3	17.7	16.8	27.4	14.9	19.8
M.d.r.	.....	......	......	ns	2.61	3.02	ns	ns	ns	ns

TABLE 5

PER CENT REDUCING SUGAR IN TOTAL DRY WEIGHT

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	4.999	6.694	3.349	2.654	1.996	2.189	2.795	2.243	1.721	1.027
A	5.794	9.115	5.760	3.990	3.641	4.204	3.866	4.904	2.334	1.219
B	.....	......	......	......	......	......	4.132	6.300	3.474	1.734
C	.....	......	......	3.894	3.817	4.284	4.913	6.288	2.741	1.614
D	.....	......	......	......	......	......	4.948	7.606	3.672	2.338
S.D.	.890	.674	.692	.939	.959	.725	.984	1.298	.732	.652
C.V.	15.4	7.4	12.0	23.8	25.7	17.1	22.0	20.7	24.0	37.8
M.d.r.	.....	......	......	ns	ns	ns	ns	1.349	.761	.678

TABLE 6

PER CENT SUCROSE IN TOTAL DRY WEIGHT

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	6.986	16.375	32.345	34.239	35.878	35.869	35.314	36.683	42.264	44.374
A	4.548	13.636	27.738	35.584	35.704	35.485	34.967	34.364	41.540	46.556
B	.....	......	......	......	......	......	34.602	31.589	40.721	45.063
C	.....	......	......	34.513	35.027	34.841	32.362	30.871	40.392	45.175
D	.....	......	......	......	......	......	32.584	29.254	39.111	46.334
S.D.	.722	1.315	1.525	2.052	1.917	1.573	2.261	3.091	1.705	2.641
C.V.	15.8	9.7	5.5	5.8	5.4	4.5	6.7	9.8	4.2	5.8
M.d.r.	.....	......	......	ns	ns	ns	ns	ns	ns	ns

TABLE 7

PER CENT TOTAL SUGARS IN TOTAL DRY WEIGHT

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	12.353	23.932	37.462	38.695	39.713	39.946	39.968	40.857	46.209	47.737
A	10.581	23.469	34.900	41.444	41.223	41.556	40.686	41.077	46.061	50.219
B	......	......	......	......	......	......	40.555	39.553	46.338	49.180
C	......	......	.....	40.236	40.725	40.927	38.993	38.778	45.259	49.092
D	......	......	......	......	......	......	39.247	38.401	44.841	51.101
S.D.	1.06	1.399	1.649	2.388	1.733	1.570	1.891	2.484	1.922	2.849
C.V.	10.0	6.0	4.7	5.9	4.2	3.8	4.7	6.3	4.2	5.7
M.d.r.	......	......	......	ns	ns	ns	ns	ns	ns	ns

TABLE 8

PER CENT NITROGEN IN TOTAL DRY WEIGHT

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	.866	.503	.311	.244	.243	.207	.172	.172	.251	.159
A	1.048	.797	.534	.406	.358	.335	.254	.276	.236	.185
B	......	......	......	......	......	......	.309	.341	.314	.231
C	......	......	......	.475	.474	.431	.365	.346	.329	.234
D	......	......	......	......	......	......	...372	.427	.413	.274
S.D.	.127	.064	.055	.055	.064	.064	.032	.045	.059	.026
C.V.	12.0	7.5	9.3	11.4	14.5	15.7	11.1	12.7	18.3	11.3
M.d.r.	......	......	......	.041	.046	.046	.035	.046	.062	.027

TABLE 9

PER CENT P_2O_5 IN TOTAL DRY WEIGHT

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	.307	.275	.191	.164	.196	.185	.180	.223	.263	.239
A	.304	.254	.170	.148	.136	.141	.130	.174	.178	.171
B	..... .	......	......	......	......	......	.140	.163	.178	.148
C	......	......	......	.146	.145	.152	.150	.171	.173	.148
D	......	......	......	......	......	......	.150	.167	.175	.143
S.D.	.024	.015	.014	.012	.010	.011	.026	.019	.018	.020
C.V.	7.9	5.9	8.2	8.2	7.8	7.5	18.6	11.2	10.2	13.1
M.d.r.	......	......	......	ns	.008	.008	ns	ns	ns	.021

TABLE 10

PER CENT K_2O IN TOTAL DRY WEIGHT

Plots	8½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	2.755	2.181	1.568	1.363	1.330	1.222	1.340	1.206	1.308	1.205
A	2.869	1.923	1.385	1.238	1.040	1.081	1.330	1.113	1.072	1.056
B	......	......	......	......	......	......	1.140	1.012	1.073	.959
C	......	......	......	1.222	1.080	1.149	1.360	1.064	1.071	.924
D	......	......	......	......	......	......	1.290	1.160	1.062	.847
S.D.	.226	.243	.263	.070	.151	.193	.138	.152	.181	.173
C.V.	7.9	12.6	19.0	5.7	14.2	17.3	10.8	13.8	16.9	18.3
M.d.r.	......	......	......	ns	ns	ns	.14	ns	ns	ns

TABLE 11

REDUCING SUGARS—TONS PER ACRE

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	.103	.393	.307	.305	.220	.282	.415	.486	.508	.327
A	.153	.829	.771	.599	.625	.904	.953	1.688	1.026	.528
B	......	......	......	......	......	......	.999	2.063	1.626	.819
C	......	......	......	.609	.755	1.064	1.155	1.896	1.217	.751
D	......	......	......	......	......	......	1.265	2.452	1.763	1.031
S.D.	.047	.176	.123	.141	.180	.205	.298	.446	.380	.272
C.V.	32.7	21.7	15.6	23.4	26.1	20.3	27.4	22.2	27.0	34.8
M.d.r.	......	......	......	ns	ns	.149	ns	.464	.395	.291

TABLE 12

SUCROSE—TONS PER ACRE

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	.147	.948	3.013	3.720	3.943	4.573	5.038	7.982	11.705	13.342
A	.114	1.215	3.686	5.275	6.038	7.664	8.678	11.777	17.539	20.410
B	......	......	......	......	......	......	8.436	10.592	19.676	22.573
C	......	......	......	5.467	7.042	8.613	7.577	9.575	18.143	20.704
D	......	......	......	......	......	......	8.329	9.922	18.258	20.643
S.D.	.036	.301	.549	1.044	1.353	1.367	1.449	3.298	2.897	4.202
C.V.	31.6	24.8	14.9	19.4	20.7	16.8	17.6	31.5	15.7	19.9
M.d.r.	......	......	......	ns	.992	ns	ns	ns	ns	ns

TABLE 13

TOTAL SUGARS—TONS PER ACRE

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	.257	1.390	3.484	4.220	4.365	5.095	5.718	8.887	12.829	14.371
A	.272	2.088	4.644	6.151	6.981	8.972	10.091	14.084	19.488	22.009
B	......	......	......	......	......	......	9.879	13.213	22.337	24.586
C	......	......	......	6.365	8.174	10.123	9.134	11.973	20.314	22.517
D	......	......	......	......	......	......	10.033	12.896	20.982	22.755
S.D.	.079	.460	.670	1.168	1.491	1.575	1.649	3.697	3.230	4.488
C.V.	28.3	22.0	14.4	18.7	19.7	16.5	16.9	28.3	15.5	19.5
M.d.r.	......	......	......	ns	1.091	1.151	ns	ns	ns	ns

TABLE 14

MILLABLE CANE—TONS PER ACRE

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X		15.91	26.91	31.19	31.22	35.96	43.01	67.60	91.98	91.22
A		25.78	39.44	44.06	51.05	67.37	79.91	119.67	140.14	136.26
B		......	......	......	......	......	77.12	121.12	166.26	157.99
C		......	......	46.46	59.96	76.45	77.51	111.12	152.33	151.15
D		......	......	......	......	......	85.44	128.73	166.07	149.60
S.D.		5.74	6.28	8.74	10.48	13.30	13.37	28.57	21.65	26.70
C.V.		22.3	15.9	19.3	18.5	18.5	16.7	23.8	13.9	17.9
M.d.r.		......	......	ns	7.7	ns	ns	ns	ns	ns

TABLE 15

COMMERCIAL SUGAR—TONS PER ACRE

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X		.51	2.10	3.01	3.28	3.58	3.81	6.22	9.41	11.07
A		.25	2.40	3.92	4.85	5.91	6.46	8.65	14.41	16.23
B		......	......	......	......	......	6.49	7.02	14.80	18.85
C		......	......	4.27	5.59	6.78	6.03	5.93	14.24	17.12
D		......	......	......	......	......	6.19	5.79	13.83	15.85
S.D.		.16	.47	.84	1.26	1.15	1.35	2.11	2.39	3.84
C.V.		64.0	19.6	20.2	24.3	18.1	21.4	31.0	16.7	22.6
M.d.r.		......	......	ns	ns	.85	ns	2.18	ns	ns

TABLE 16

YIELD PER CENT CANE

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X		3.2	7.8	9.7	10.5	10.1	9.1	9.1	10.4	12.0
A		0.9	6.1	9.0	9.5	8.8	8.2	7.3	10.4	11.9
B		......	......	......	......	......	8.4	5.9	8.9	11.9
C		......	......	9.2	9.3	8.9	7.2	5.4	9.3	11.3
D		......	......	......	......	......	7.2	4.4	8.3	10.6
S.D.		.5	.8	.7	1.1	.9	1.3	1.1	.6	1.2
C.V.		50.0	13.4	7.3	11.8	11.0	16.8	19.3	6.6	10.3
M.d.r.		......	......	ns	ns	ns	ns	1.1	.6	ns

TABLE 17

NITROGEN IN TOTAL DRY WEIGHT—POUNDS PER ACRE

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	35.1	58.1	57.4	53.9	52.6	54.1	50.9	75.7	138.5	96.1
A	53.2	140.2	143.2	120.5	119.7	144.4	125.5	188.8	201.8	159.9
B	......	......	......	......	......	......	150.5	224.1	302.1	228.0
C	......	......	......	148.6	187.3	214.1	170.7	209.7	296.1	212.1
D	......	......	......	......	......	......	187.5	285.9	394.0	247.7
S.D.	10.2	18.7	26.0	24.5	24.1	42.6	32.2	62.1	78.1	44.1
C.V.	19.0	13.3	18.1	18.2	15.7	23.8	20.3	27.4	26.2	20.8
M.d.r.	......	......	......	17.9	17.6	31.2	33.5	64.6	81.2	45.8

TABLE 18

P_2O_5 IN TOTAL DRY WEIGHT—POUNDS PER ACRE

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	12.5	31.5	35.4	35.1	42.6	48.9	52.8	98.9	148.3	141.5
A	15.5	44.8	45.3	44.6	46.2	61.5	65.4	118.8	149.7	147.0
B	......	......	......	......	......	......	64.8	108.4	170.9	147.7
C	......	......	......	45.7	58.4	75.8	70.7	105.5	155.1	133.5
D	......	......	......	......	......	......	76.3	114.8	166.9	129.7
S.D.	3.0	7.8	6.7	9.9	11.0	15.6	17.0	34.3	27.6	28.1
C.V.	19.4	17.4	14.7	21.9	21.1	22.7	24.5	30.7	17.1	20.2
M.d.r.	......	......	......	ns	8.1	11.4	ns	ns	ns	ns

TABLE 19

K_2O IN TOTAL DRY WEIGHT—POUNDS PER ACRE

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	112.4	249.0	291.0	292.5	286.4	322.2	388.8	532.7	730.5	721.2
A	146.2	338.6	366.5	367.1	349.6	468.6	656.9	762.9	902.8	905.2
B	......	......	......	......	......	......	555.9	677.2	1024.7	955.9
C	......	......	......	381.4	435.3	569.5	623.9	658.2	968.0	836.7
D	......	......	......	......	......	......	651.2	796.8	990.0	771.7
S.D.	36.1	77.2	64.6	92.5	93.4	134.9	110.5	229.7	186.7	203.4
C.V.	24.7	22.8	17.6	24.7	23.8	26.0	17.8	31.7	19.2	23.5
M.d.r.	......	......	......	ns	68.3	98.7	ns	ns	ns	ns

TABLE 20

PER CENT NITROGEN IN LEAF-PUNCH SAMPLES

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	1.76	1.71	1.45	1.16	1.03	.98	.97	1.15	1.18	.90
A	1.99	1.96	1.77	1.55	1.44	1.36	1.31	1.35	1.40	1.06
B	......	......	......	......	......	......	1.43	1.46	1.51	1.17
C	......	......	......	1.58	1.51	1.46	1.41	1.45	1.54	1.16
D	......	......	......	......	......	......	1.52	1.54	1.62	1.20
S.D.	.11	.06	.06	.04	.04	.06	.05	.06	.07	.06
C.V.	5.5	3.1	3.4	2.6	3.4	4.3	3.5	4.3	4.6	5.2
M.d.r.	......	......	......	.03	.03	.05	.05	.07	.07	.06

TABLE 21

PER CENT NITROGEN IN CRUSHER JUICE

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X		.011	.011	.009	.009	.008	.006	.006	.009	.009
A		.036	.030	.025	.023	.018	.013	.011	.012	.014
B		......	......	......	......	......	.017	.018	.018	.019
C		......	......	.034	.035	.030	.022	.019	.019	.020
D		......	......	......	......	......	.023	.027	.026	.027
S.D.		.008	.007	.009	.008	.008	.004	.004	.003	.004
C.V.		22.2	26.7	31.0	27.6	30.4	21.1	21.0	15.8	18.5
M.d.r.		......	......	.006	.006	.006	.004	.004	.003	.004

TABLE 22

PER CENT CHLOROPHYLL IN GREEN-LEAF BLADES

Plots	3½ mos. Nov.	5½ mos. Jan.	7½ mos. March	8½ mos. April	9½ mos. May	10½ mos. June	11½ mos. July	14½ mos. Oct.	17½ mos. Jan.	20½ mos. April
X	.071	.086	.085	.084	.062	.064	.062	.086	.098	.049
A	.087	.124	.120	.101	.091	.088	.089	.102	.123	.064
B	......	......	......	......	......	......	.099	.116	.123	.075
C	......	......	......	.108	.103	.098	.089	.119	.132	.077
D	......	......	......	......	......	......	.091	.123	.143	.078
S.D.	.001	.002	.001	.008	.008	.009	.012	.017	.018	.010
C.V.	11.9	13.0	9.9	7.3	8.6	10.3	13.0	14.8	13.4	13.2
M.d.r.	......	......	......	.006	.006	.007	ns	ns	ns	.010

Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
JUNE 16, 1942 TO SEPTEMBER 15, 1942

Date	Per pound	Per ton	Remarks
June 15 - Sept. 15, 1942........	3.74¢	$74.80	Philippines

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